



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY  
REGION III  
1650 Arch Street  
Philadelphia, Pennsylvania 19103-2029



MAR 09 2001

Mr. Larry Lawson  
Virginia Department of Environmental Quality  
629 Main Street  
Richmond, VA 23219

Re: Mill Creek and Pleasant Run TMDLs, Rockingham County



Dear Mr. Lawson:

The Environmental Protection Agency (EPA) Region III, is pleased to approve the fecal coliform TMDLs for Mill Creek and Pleasant Run. These TMDLs were submitted for EPA review on February 08, 2001. These TMDLs were established and submitted in accordance with section 303 (d)(1)(c) and (2) of the Clean Water Act. These TMDLs were established to address an impairment of water quality as identified in Virginia's 1998 Section 303 (d) list. Virginia identified multiple impairments for each of these water quality-limited segments within the North River watershed. Both waters are listed for exceedances of the fecal coliform water quality standard and an impaired benthic community. In order for these TMDLs to fulfill the Commonwealth's commitments established in the MOU, all of the impairments must be addressed. Therefore, a TMDL must be developed on each of these streams for the benthic impairment in order for them to fulfill a commitment. If data demonstrates that the benthic community (of these streams) is no longer impaired, a TMDL may not be needed.

In accordance with Federal Regulations in 40 CFR §130.7, a TMDL must be designed to meet water quality standards, and (1) include, as appropriate wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources, (2) consider the impacts of background pollutant contributions, (3) take critical stream conditions into account (the conditions when water quality is most likely to be violated), (4) consider seasonal variations, (5) include a margin of safety (which accounts for uncertainties in the relationship between pollutant loads and instream water quality), and be subject to public participation. The enclosures accompanying this letter describe how the TMDLs for Mill Creek and Pleasant Run satisfy each of these requirements.

Following the approval of this TMDL, Virginia shall incorporate the TMDL into the Water Quality Management Plan pursuant to 40 CFR § 130.7(d)(2). As you know, any new or revised National Pollutant Discharge Eliminations Systems (NPDES) permit must be consistent with the TMDLs Waste Load Allocation pursuant to 40 CFR §122.44 (d)(1)(vii)(B). Please submit all such permits to EPA for review as per EPA's letter dated October 1, 1998. Please feel free to contact Thomas Henry at 215-814-5752, if you have any questions or comments.

Sincerely,

  
Rebecca Hamner, Director  
Water Protection Division 

Enclosures

## **Decision Rationale**

### **Total Maximum Daily Load of Fecal Coliform for Mill Creek**

#### **I. Introduction**

This document will set forth the Environmental Protection Agency's (EPA) rationale for approving the Total Maximum Daily Load (TMDL) of Fecal Coliform for Mill Creek submitted for final Agency review on February 08, 2001. Our rationale is based on the TMDL submittal document to determine if the TMDL meets the following 8 regulatory conditions pursuant to 40 CFR §130.

1. The TMDLs are designed to implement applicable water quality standards.
2. The TMDLs include a total allowable load as well as individual waste load allocations and load allocations.
3. The TMDLs consider the impacts of background pollutant contributions.
4. The TMDLs consider critical environmental conditions.
5. The TMDLs consider seasonal environmental variations.
6. The TMDLs include a margin of safety.
7. The TMDLs have been subject to public participation.
8. There is reasonable assurance that the TMDLs can be met.

#### **II. Background**

Located in Rockingham County, Virginia, the overall Mill Creek watershed is approximately 9,633 acres. The TMDL addresses 2.66 miles of Mill Creek beginning at its headwaters and continuing to its confluence with the North River. Agriculture is the dominant land use in the watershed. Mill Creek is a tributary to the North River which flows into the S.F. Shenandoah, which flows into the Potomac, which discharges to the Chesapeake Bay.

In response to Section 303 (d) of the Clean Water Act (CWA), the Virginia Department of Environmental Quality (VADEQ) listed 2.66 miles of Mill Creek as being impaired by elevated levels of fecal coliform on Virginia's 1998 303 (d) list. Mill Creek was listed for violations of Virginia's fecal coliform bacteria standard for primary contact. Fecal coliform is a bacterium which can be found within the intestinal tract of all warm blooded animals. Fecal coliform can therefore be found in the fecal wastes of warm blooded animals. Fecal coliform in itself is not a pathogenic organism. However, fecal coliform indicates the presence of fecal wastes and the potential for the existence of other pathogenic bacteria. The higher concentrations of fecal coliform indicate the elevated likelihood of increased pathogenic organisms. Mill Creek, identified as watershed VAV-B29R, was given a high priority for TMDL development. Section 303 (d) of the Clean Water Act and its implementing regulations require a TMDL to be developed for those waterbodies identified as impaired by the State where technology-based and other controls do not provide for the attainment of Water Quality Standards. The TMDL submitted by Virginia is designed to determine the acceptable load of fecal coliform which can be delivered to Mill Creek, as demonstrated by the Hydrologic

Simulation Program Fortran (HSPF)<sup>1</sup>, in order to ensure that the water quality standard is attained and maintained. These levels of fecal coliform will ensure that the Primary Contact usage is supported. HSPF is considered an appropriate model to analyze this watershed because of its dynamic ability to simulate both watershed loading and receiving water quality over a wide range of conditions.

EPA has been encouraging the States to use e-coli and enterococci as the indicator species instead of fecal coliform. A better correlation has been drawn between the concentrations of e-coli (and enterococci) and the incidence of gastrointestinal illness. The Commonwealth is pursuing changing the standard from fecal coliform to e-coli.

Virginia designates all of its waters for primary contact, therefore all waters must meet the current fecal coliform standard for primary contact. Virginia's standard is to apply to all streams designated as primary contact for all flows. Through the development of this and other similar TMDLs it was discovered that natural conditions (wildlife contributions to the streams) were causing violations of the standard during low flows. Thus many of Virginia's TMDLs have called for some reduction in the amount of wildlife contributions to the stream. EPA believes that a significant reduction in wildlife is not practical and will not be necessary due to implementation discussion below.

A phased implementation plan will be developed for all streams in which the TMDL calls for reductions in wildlife. The first phase of the implementation will reduce all sources of fecal coliform to the stream other than wildlife. In phase 2, which can occur concurrently to phase 1, the Commonwealth will consider addressing its standards to accommodate this natural loading condition. During phase 2, the Commonwealth has indicated that it will evaluate the following items in relation to the standard. 1) The possibility of placing a minimum flow requirement upon the bacteriological standard. As a result, the standard may not apply to flows below the minimum (possibly 7Q10). This application of the standard is applied in many States. 2) The Commonwealth may develop a Use Attainability Analysis (UAA) for streams with wildlife reductions which are not used for frequent bathing. Depending upon the result of that UAA, it is possible that these streams could be designated primary contact infrequent bathing. 3) The Commonwealth will also investigate incorporating a natural background condition for the bacteriological indicator.

After the completion of phase 1 of the implementation plan the Commonwealth will monitor to determine if the wildlife reductions are actually necessary, as the violation rate associated with the wildlife loading may be smaller than the percent error of the model. In phase 3, the Commonwealth will investigate the sampling data to determine if further load reductions are needed in order for these waters to attain standards. If the load reductions and/or the new application of standards allow the stream to attain standards, then no additional work is warranted. However, if standards are still not being

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<sup>1</sup>Bicknell, B.R., J.C. Imhoff, J.L. Little, and R.C. Johanson. 1993. Hydrologic Simulation Program-FORTRAN (HSPF): User's Manual for release 10.0. EPA 600/3-84-066. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

attained after the implementation of phases 1 and 2 further work and reductions will be warranted.

The TMDL analysis allocates the application/deposition of fecal coliform to land based and instream sources. For land based sources the HSPF model accounts for the buildup and washoff of pollutants from these areas. Build up (accumulation) refers to all of the complex spectrum of dry-weather processes that deposit or remove pollutants between storms. Washoff is the removal of fecal coliform which occurs as a result of runoff associated with storm events. These two processes allow the HSPF model to determine the amount of fecal coliform from land based sources which is reaching the stream. Point sources and wastes deposited directly to the stream were treated as direct deposits. These wastes did not need a transport mechanism to allow them to reach the stream. The allocation plan calls for the reduction in fecal coliform wastes delivered by cattle in-stream and wildlife in-stream. Wildlife loading alone cause violations in the standard.

Table #1 summarizes the specific elements of the TMDL.

Parameter	TMDL(cfu/yr)	WLA(cfu/yr)	LA(cfu/yr)	MOS <sup>1</sup> (cfu/yr)
Fecal Coliform	1,681.0 x 10 <sup>12</sup>	0.0	1,597.0 x 10 <sup>12</sup>	84.0 x 10 <sup>12</sup>

<sup>1</sup> Virginia includes an explicit MOS by identifying the TMDL target as achieving the total fecal coliform water quality concentration of 190 cfu/100ml as opposed to the WQS of 200 cfu/ml. This can be viewed explicitly as a 5% MOS.

EPA believes it is important to recognize the conceptual difference between directly deposited loads (loads deposited to the stream) and land applied loads. Directly deposited loads represent the actual amount of fecal coliform being deposited into the stream segments. While values for flux sources (land applied sources) represent the amount of fecal coliform deposited to land. The actual amount of fecal coliform which reaches the stream will be less than the amount of fecal coliform deposited to land due to die-off, geography (distance to the stream), soil, and application method. The HSPF model, which considers landscape processes which affect the total amount of fecal coliform runoff from land uses, determines the amount of fecal coliform which will reach the stream segment. Table 6.3 of the TMDL report illustrates the actual amounts of fecal coliform being transported to Mill Creek.

The United States Fish and Wildlife Service has been provided with a copy of this TMDL.

### III. Discussion of Regulatory Conditions

EPA finds that Virginia has provided sufficient information to meet all of the 8 basic requirements for establishing a fecal coliform TMDL for Mill Creek. EPA is therefore approving this TMDL. Our approval is outlined according to the regulatory requirements listed below.

*1) The TMDL is designed to meet the applicable water quality standards.*

Virginia has indicated that excessive levels of fecal coliform due to nonpoint sources (directly deposited into the River) have caused violations of the water quality standards and designated uses on Mill Creek. The water quality criterion for fecal coliform is a geometric mean 200 cfu (colony forming units)/100ml or an instantaneous concentration of no more than 1,000 cfu/100ml. Two or more samples over a thirty-day period are required for the geometric mean standard. Therefore, most violations of the State's water quality standard are due to violations of the instantaneous standard.

The HSPF model was used to determine the fecal coliform deposition rates to the land as well as loadings to the stream from point and direct deposition sources necessary to support the fecal coliform water quality criterion and primary contact use. The following discussion is intended to describe how controls on the loading of fecal coliform to Mill Creek will ensure that the criterion is attained.

The TMDL modelers determined the fecal coliform production rates within the watershed. Information was attained from a wide array of sources on the farm practices in the area (land application rates of manure), the amount and concentration of farm animals, point sources in the watershed, animal access to the stream, wildlife in the watershed and their fecal production rates, land uses, weather, stream geometry, etc. This information was put into the model. The model then combines all the data to determine the hydrology and water quality of the stream.

The hydrology component of the model for all the North River TMDLs (Dry River, Mill Creek, and Pleasant Run) was developed on Linville Creek using flow data from 1991 through 1996 and then transferred to each individual watershed. This was done because there were no stream gages on the other waters. When the simulated data on Linville accurately reflected the observed flow data the model was considered complete and transferred to the other watersheds. To verify the transferability of the model, the model was run on Muddy Creek (flow data from 1993 to 1995) and Linville Creek (flow data from 1986 to 1991). The percent error between observed and simulated flows for both validation runs were within the desired criterion of 10%. The winter simulated flow for Muddy Creek was significantly greater (above the 10% desired range) than the observed flow. This may have been caused by a combination of the unusual weather patterns exhibited during the winters of 1994 and 1995 and the short duration of the validation period. The hydrologic parameters were adjusted to match the conditions in each watershed. The model was calibrated by comparing simulated flow results to observed flows(monthly samples).

The model was then transferred to the Mill Creek watershed. The simulated flow data was compared to the 37 monthly flow measurements collected from Mill Creek. Based on this analysis, it was determined that the model was over predicting base flow on Mill Creek. Therefore, two of the hydrology parameters (DEEPFR and IRC) were adjusted to provide a better correlation between the observed and simulated data. By

increasing these parameters the modelers removed a portion of groundwater and interflow from the system, lowering base flow.

EPA believes that using HSPF to model and allocate fecal coliform will ensure that the designated uses and water quality standards will be attained and maintained for Mill Creek.

*2) The TMDL includes a total allowable load as well as individual waste load allocations and load allocations.*

#### Total Allowable Loads

Virginia indicates that the total allowable loading of fecal coliform is the sum of the loads allocated to land based, precipitation driven nonpoint source areas (cropland, pasture (1, 2, and 3), loafing lots, rural residential, forest) from flux sources, directly deposited nonpoint sources of fecal coliform (cattle in-stream and wildlife in-stream), and point sources. Activities such as the application of manure, fertilizer, and the direct deposition of wastes from grazing animals are considered fluxes to the land use categories. The actual value for the total fecal load can be found in Table #1 of this document. The total allowable load is calculated on an annual basis due to the nature of HSPF model.

#### Waste Load Allocations

Virginia has stated that there are no point sources discharging to Mill Creek. EPA regulations require that an approvable TMDL include individual WLAs for each point source. According to 40 CFR 122.44(d)(1)(vii)(B), “Effluent limits developed to protect a narrative water quality criterion, a numeric water quality criterion, or both, are consistent with assumptions and requirements of any available WLA for the discharge prepared by the State and approved by EPA pursuant to 40 CFR 130.7.” Furthermore, EPA has authority to object to the issuance of any NPDES permit that is inconsistent with the WLAs established for that point source

#### Load Allocations

According to federal regulations at 40 CFR 130.2 (g), load allocations are best estimates of the loading, which may range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading. Wherever possible natural and nonpoint source loads should be distinguished.

In order to accurately simulate landscape processes and nonpoint source loadings, VADEQ used the HSPF model to represent the Mill Creek watershed. The HSPF model is a comprehensive modeling system for simulation of watershed hydrology, point and nonpoint loadings, and receiving water quality for conventional pollutants and toxicants<sup>2</sup>.

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<sup>2</sup> Supra, footnote 2.

More specifically HSPF uses precipitation data for continuous and storm event simulations to determine total fecal loading to Mill Creek from impervious areas, cropland, forest, pasture (1, 2, and 3) loafing lots, rural residential, farmstead, etc. The total land loading of fecal coliform is the result of the application of manure (cattle and poultry wastes), direct deposition from cattle and wildlife (geese, duck, racoon, muskrat, and deer) to the land, fecal coliform production from dogs, and septic system failure.

In addition, VADEQ recognizes the significant loading of fecal coliform from cattle in-stream and wildlife in-stream. These sources are not dependent on a transport mechanism to reach a surface waterbody and therefore impact water quality during low and high flow events. These sources were modeled as though they were point sources.

Climatic data was obtained from the Dale Enterprise weather station. This weather station is located 12.8 miles from the watershed outlet. Precipitation acts as a transport mechanism for land applied loads. Therefore, weather data plays an integral part in the modeling process, affecting the loading to the stream. The average annual precipitation is 33.6 inches with approximately 60% of the precipitation occurring from May to October. Additional climatological information was obtained from weather stations in Monterey Virginia, Lynchburg Airport, and Elkins Airport (West Virginia).

Table #2 - Load allocation for the land application of fecal coliform

Source	Existing Load (cfu/yr)	Allocated Load(cfu/yr)	Percent Reduction
Cropland	77.8E+12	77.8E+12	0%
Pasture 1	1,307.8E+12	1,307.8E+12	0%
Pasture 2	110.7E+12	110.7E+12	0%
Pasture 3	48.0E+12	48.0E+12	0%
Loafing Lots	0.1E+12	0.1E+12	0%
Rural Residential	32.2E+12	32.2E+12	0%
Farmstead	2.7E+12	2.7E+12	0%
Forest	3.9E+12	3.9E+12	0%
Urban Residential	10.6E+12	10.6E+12	0%
Wildlife In-Stream	10.8E+12	3.2E+12	70%
Cattle In-Stream	133.5E+12	0.0	100%

*3) The TMDL considers the impacts of background pollution.*

The Mill Creek TMDL considered background as being pristine forested conditions. Wildlife was the source of fecal loading for background conditions.

*4) The TMDL considers critical environmental conditions.*

EPA regulations at 40 CFR 130.7 (c)(1) require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of Mill Creek is protected during times when it is most vulnerable.



Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and will help in identifying the actions that may have to be undertaken to meet water quality standards<sup>3</sup>. Critical conditions are a combination of environmental factors (e.g., flow, temperature, etc.), which have an acceptably low frequency of occurrence but when modeled to, insure that water quality standards will be met for the remainder of conditions. In specifying critical conditions in the waterbody, an attempt is made to use a reasonable “worst-case” scenario condition. For example, stream analysis often uses a low-flow (7Q10) design condition because the ability of the waterbody to assimilate pollutants without exhibiting adverse impacts is at a minimum.

The sources of bacteria for these stream segments were mixtures of dry and wet weather driven sources. The TMDL was modeled to a typical hydrologic year. The Mill Creek watershed is dominated by low flow events. Therefore, if the fecal coliform standard was attained during these low flow events, it would be attained for the year. Low flow events represent the critical condition for Mill Creek.

*5) The TMDLs consider seasonal environmental variations.*

Seasonal variations involve changes in stream flow as a result of hydrologic and climatological patterns. In the continental United States, seasonally high flow normally occurs in early spring from snow melt and spring rain, while seasonally low flow typically occurs during the warmer summer and early fall drought periods. Consistent with our discussion regarding critical conditions, the HSPF model and TMDL analysis effectively considered seasonal environmental variations. The TMDL clearly considered seasonal environmental variations as the model for Mill Creek was run from 1993 through 1996. The model also accounted for the seasonal variation in loading. Fecal coliform loads changed for many of the sources depending on the time of the year. For example, cattle spent more time in the stream in the summer and animals were confined for longer periods of time in the winter.

*6) The TMDLs include a margin of safety.*

This requirement is intended to add a level of safety to the modeling process to account for any uncertainty. Margins of safety may be implicit, built into the modeling process by using conservative modeling assumptions, or explicit, taken as a percentage of the wasteload allocation, load allocation, or TMDL.

Virginia used an explicit margin of safety by establishing the TMDL target water quality concentration for fecal coliform at 190 cfu/ 100mL, which is more stringent than Virginia’s water quality standard of 200 cfu/100 mL.

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<sup>3</sup>EPA memorandum regarding EPA Actions to Support High Quality TMDLs from Robert H. Wayland III, Director, Office of Wetlands, Oceans, and Watersheds to the Regional Management Division Directors, August 9, 1999.

*7) The TMDLs have been subject to public participation.*

This TMDL was subject to a number of public meetings. Three public meetings were held in Dayton, VA. The meetings were held on December 09, 1999, January 20, 2000, and March 28, 2000 and were intended to address initial questions and concerns regarding outreach issues and the TMDL process.

The first public meeting was held on December 9, 1999 in Dayton and was announced in the Virginia Register on November 03, 1999. The second public meeting was announced in the Virginia Register on December 14, 1999. The March 28, 2000, public meeting was announced in the March 13, 2000 Virginia Register and the local. No written comments were submitted by the general public.

*8) There is a reasonable assurance that the TMDL can be met.*

EPA requires that there be a reasonable assurance that the TMDL can be implemented. WLAs will be implemented through the NPDES permit process. According to 40 CFR 122.44(d)(1)(vii)(B), the effluent limitations for an NPDES permit must be consistent with the assumptions and requirements of any available WLA for the discharge prepared by the state and approved by EPA. Furthermore, EPA has authority to object to issuance of an NPDES permit that is inconsistent with WLAs established for that point source.

Nonpoint source controls to achieve LAs can be implemented through a number of existing programs such as Section 319 of the Clean Water Act, commonly referred to as the Nonpoint Source Program. Additionally, Virginia's Unified Watershed Assessment, an element of the Clean Water Action Plan, could provide assistance in implementing this TMDL.

# **Fecal Coliform TMDL for Mill Creek Rockingham County, Virginia**

**Submitted by**

**Virginia Department of Environmental Quality  
Virginia Department of Conservation and Recreation**

**Prepared by**

**Virginia Tech  
Department of Biological Systems Engineering  
and  
Department of Biology**

**December 2000**

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Rockingham Co. Department of Health – Bill Ringle

University of Virginia - Teresa Culver

VADCR - Mark Bennett, Richard Fitzgerald, Charlie Wade

VADEQ - Rod Bodkin, Dave Lazarus, Charles Martin, Tom Mizell, Roger Stewart,

Michelle Titman

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# **1. EXECUTIVE SUMMARY**

## **1.1. Background**

Located in Rockingham County, Virginia, the Mill Creek watershed (VAV-B29R, 9,633 acres) is about 2.9 miles south-southeast of city of Harrisonburg. Mill Creek is a tributary of North River. The North River is a tributary of the South Fork of the Shenandoah River (USGS Hydrologic Unit Code 02070005), which in turn, is a tributary of the Potomac River. The Potomac River discharges into the Chesapeake Bay.

Water quality samples collected in Mill Creek, over five years (September 1993 – December 1998) indicated that 62% of the samples violated the instantaneous criterion of the water quality standard pertaining to fecal coliform. The instantaneous criterion specifies that fecal coliform concentration in the stream water shall not exceed 1,000 coliform forming units (cfu) per 100 mL. Due to the high frequency of water quality violations, Mill Creek has been placed on Virginia's 1998 303(d) list of impaired waterbodies for fecal coliform. The impairment starts at the headwaters and continues downstream to its confluence with North River, for a total of 2.66 stream miles.

As a result of the water quality impairment, Mill Creek was assessed as not supporting the Clean Water Act's Swimming Use Support Goal for the 1998 305(b) report and was included in the 303(d) list (USEPA, 1998a, b). In order to remedy the water quality impairment pertaining to fecal coliform, a Total Maximum Daily Load (TMDL) has been developed, taking into account all sources of fecal coliform and a margin of safety (MOS). Upon implementation, the TMDL plan for Mill Creek will ensure that the water quality standard relating to fecal coliform will be in compliance with the geometric mean standard. The geometric mean standard specifies that the 30-day geometric mean concentration of fecal coliform shall not exceed 200 cfu/100mL.

## **1.2. Sources of Fecal Coliform**

Since there are no permitted point sources of fecal coliform in the Mill Creek watershed, the fecal coliform load is entirely originated from nonpoint sources. The nonpoint sources of fecal coliform are mainly agricultural, such as, land-applied animal waste and manure

deposited on pastures by cattle. A significant fecal coliform load comes from cattle directly depositing in streams. Wildlife contribute to fecal coliform loadings on pasture, forest, and stream. Non-agricultural nonpoint sources of fecal coliform loadings include failing septic systems and pet waste. The amounts of fecal coliform produced in different locations (e.g., confinement, pasture, forest) were estimated on a monthly basis to account for seasonal variability in production and practices, considering factors such as the fraction of time cattle are in confinement, time spent in streams, and manure storage and spreading schedules.

### **1.3. Modeling**

The Hydrologic Simulation Program – FORTRAN (HSPF) was used to simulate the fate and transport of fecal coliform bacteria in the Mill Creek watershed. The BASINS (Better Assessment Science Integrating Point and Nonpoint Sources System) Version 2.0 interface was used to facilitate use of HSPF. To identify localized sources of fecal coliform within the Mill Creek watershed, the watershed was divided into six subwatersheds, based on homogeneity of land-use.

Due to the short period of flow record available for Mill Creek, the hydrology component of HSPF was calibrated for Linville Creek, a tributary of North Fork of the Shenandoah River, which had a longer period of record. The HSPF was calibrated for Linville Creek using data from a 4.5-year period. The calibration period covered a wide range of hydrologic conditions, including low- and high-flow conditions as well as seasonal variations. The calibrated HSPF data set was validated on a separate period of record for Linville Creek (5 years) and Muddy Creek (3+ years), also a North River tributary. The calibrated HSPF model adequately simulated the hydrology of the Mill Creek watershed.

The water quality component of HSPF was calibrated using three years (September 1993 – July 1996) of fecal coliform data collected in the watershed. Inputs to the model included fecal coliform loadings on land and in the stream and simulated flow data. A comparison of simulated and observed fecal coliform loadings in the stream indicated that the model adequately simulated the fate of fecal coliform in the watershed.

#### **1.4. Existing Conditions**

Based on amounts of fecal coliform produced in different locations, monthly fecal coliform loadings to different land-use categories were calculated for each subwatershed for input into the model. Fecal coliform content of stored waste was adjusted to account for die-off during storage at the time of application. Similarly, fecal coliform die-off on land was taken into account, as was the reduction in fecal coliform due to subsurface application. Direct fecal coliform loadings to streams by cattle varied by the season and location of pastures. Fecal coliform loadings in the stream or on land by wildlife were estimated for deer, raccoon, muskrat, goose, and wood duck. Fecal coliform loading to land from failing septic systems were estimated based on number and age of houses. Fecal coliform contribution from pet waste was also considered.

Contributions from various sources were represented in HSPF to establish the existing conditions for the representative hydrologic period of nearly three years (September 1993 – July 1996). The simulation results indicated that the mean daily fecal coliform concentration at the watershed outlet was 4,977 cfu/100 mL compared with an average fecal coliform concentration of 4,170 cfu/100mL observed during the simulation period. Since the water quality samples had caps of 8,000 cfu/100 mL (before February 1995) or 16,000 cfu/100 mL, the average observed value could have been higher. Cattle directly depositing in the stream contributed 92.1% of the mean daily fecal coliform concentration; contribution from upland areas due to runoff accounted for 4.8% while wildlife defecating in the stream accounted for the remaining 3.1%. Observed and simulated fecal coliform concentrations exceeded the 30-day geometric mean water quality standard more frequently during low flow periods and the summer. During the summer, when stream flow was lower, cattle spent more time in streams, and thereby increased direct fecal coliform deposition to streams when water for dilution was least available.

#### **1.5. Margin of Safety**

While developing allocation scenarios to implement the TMDL, an explicit margin of safety (MOS) of 5% was used. Hence, the maximum 30-day geometric mean target for the allocation scenario was 190 cfu/100 mL, 5% below the standard (200 cfu/100 mL). It

is expected that a MOS of 5% will account for any uncertainty involved in the accuracy of the input data used in the model.

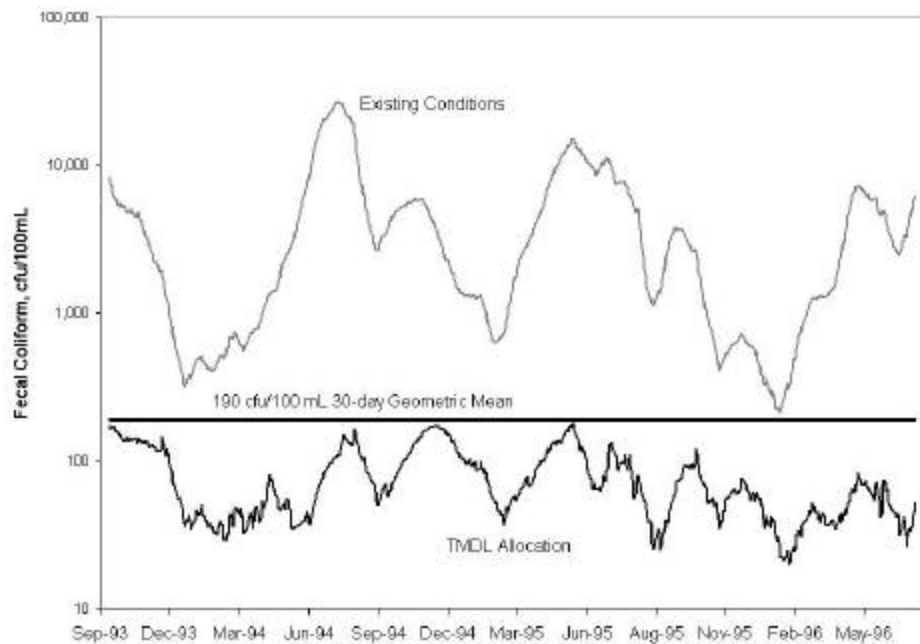
## 1.6. Allocation Scenarios

After calibrating to the existing water quality conditions, different scenarios were evaluated to identify implementable scenarios that meet the 30-day geometric mean criterion (200 cfu/100 mL) with zero violations. The scenarios are presented in Table 1.1.

**Table 1.1. Allocation scenarios for Mill Creek watershed**

Scenario Number	Percent Reduction in Loading from Existing Condition				
	Direct wildlife deposits	Direct cattle deposits	NPS from pervious land segments	NPS from impervious land segments	Percentage of days with 30-day GM > 190 cfu/100mL
<b>1</b>	0.0	100.0	100.0	100.0	39.9
<b>2</b>	25.0	96.5	0.0	0.0	60.5
<b>3</b>	75.0	99.0	0.0	0.0	16.0
<b>4</b>	<b>70.0</b>	<b>100.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>

In Scenario 1, contributions from all other sources of fecal coliform loadings in the model were turned off, except for fecal coliform deposited directly in the stream by wildlife. Frequent violations of the 30-day geometric mean goal (39.9%) by wildlife alone indicates that it is not possible to develop a TMDL that meets the current state water quality standards only by reducing sources of fecal coliform caused by human activity. In consultation with VADCR, allocation scenarios (Scenarios 2, 3, and 4) were developed that require reductions in both human (including livestock) and natural (wildlife) sources of fecal coliform. Scenario 4 (Table 1.1) meets the TMDL allocation requirement of no violation of the 190 cfu/100mL 30-day geometric mean goal with modest reduction in fecal coliform load from wildlife. Scenario 4 requires complete exclusion of cattle from the stream; however, no reduction in fecal coliform loading from upland area is required. Fecal coliform concentrations resulting from Scenario 4 as well as the existing conditions are presented graphically in Figure 1.1. Fecal coliform loads from nonpoint and direct nonpoint sources under existing conditions and for the allocation scenario (Scenario 4) are presented in Tables 1.2 and 1.3.



**Figure 1.1. Successful TMDL allocation (Scenario 4, Table 1.1), 190 cfu/100 mL geometric mean goal, and existing conditions for Mill Creek**

**Table 1.2. Annual nonpoint source loads under existing conditions and corresponding reductions for TMDL allocation scenario 4.**

Land-use Category	Existing conditions		Allocation scenario	
	Existing load ( $\times 10^{12}$ cfu)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load ( $\times 10^{12}$ cfu)	Percent reduction from existing load
<b>Cropland</b>	77.8	4.9	77.8	0.0
<b>Pasture 1</b>	1307.8	82.0	1307.8	0.0
<b>Pasture 2</b>	110.7	6.9	110.7	0.0
<b>Pasture 3</b>	48.0	3.0	48.0	0.0
<b>Farmstead</b>	2.7	0.2	2.7	0.0
<b>Rural Residential</b>	32.2	2.0	32.2	0.0
<b>Urban Residential</b>	10.6	0.7	10.6	0.0
<b>Loafing Lot</b>	0.1	<.01	0.1	
<b>Forest</b>	3.9	0.2	3.9	0.0
<b>Total</b>	<b>1,593.8</b>	<b>100.0</b>	<b>1,593.8</b>	<b>0.0</b>



**Table 1.3. Annual direct nonpoint source loads under existing conditions and corresponding reductions for TMDL allocation scenario 4.**

Source	Existing conditions load ( $\times 10^{12}$ cfu)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load ( $\times 10^{12}$ cfu)	Percent reduction
Cattle in Streams	133.5	92.5	0	100.0
Wildlife in Streams	10.8	7.5	3.2	70.0
<b>Total</b>	<b>144.3</b>	<b>100.0</b>	<b>3.2</b>	<b>97.8</b>

For the selected scenario (Scenario 4), load allocations were calculated using the following equation.

$$\text{TMDL} = \Sigma \text{WLA} + \Sigma \text{LA} + \text{MOS} \quad [1.1]$$

where,

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety, 5% of TMDL.

Since there are no point sources of fecal coliform in Mill Creek watershed, the proposed scenario requires load allocations for only the nonpoint source contributions. Based on reductions required from existing conditions and fecal coliform loadings given in Tables 1.2 and 1.3, the summary of fecal coliform TMDL is given in Table 1.4.

**Table 1.4. Annual fecal coliform loadings (cfu/year) for the Mill Creek fecal coliform TMDL**

Parameter	SWLA	SLA	MOS <sup>a</sup>	TMDL
Fecal coliform	0	$1597.0 \times 10^{12}$	$84.0 \times 10^{12}$	$1681.0 \times 10^{12}$

<sup>a</sup> Five percent of TMDL

The proposed scenario requires no reductions in fecal coliform loads from nonpoint sources. To achieve reductions in the direct nonpoint source loads, complete exclusion of cattle from stream as well as 70% reduction in direct fecal coliform loading to the stream by wildlife are required.

### **1.7. Phase 1 Implementation**

An alternative scenario was evaluated that requires less drastic changes in management practices and achieves smaller reduction in fecal coliform concentration in the stream. The implementation of such a transitional scenario, or Phase 1 implementation, will allow for an evaluation of the effectiveness of management practices and accuracy of model assumptions through data collection. Phase 1 implementation was developed for a maximum of 10% violations of the instantaneous criterion (1,000 cfu/100 mL) based on monthly sampling frequency. Phase 1 implementation requires 96.5% reduction in direct fecal coliform loading by cattle into the stream. No reductions in loading from wildlife to the stream or from upland nonpoint sources are required.

### **1.8. Reasonable Assurance of Implementation**

A phased TMDL implementation plan has been developed that allows for the interim evaluation of the effectiveness of the proposed TMDL implementation while progressing toward compliance with Virginia's water quality standard. Phase 1 implementation allows for the evaluation of the effectiveness of management practices through stream monitoring on a monthly basis. Also, data collection during this phase allows for the quantification of uncertainties that affect TMDL development. By accounting for such uncertainties, the TMDL can be improved for the final implementation phase that requires full compliance with the 200 cfu/100 mL geometric mean water quality standard.

### **1.9. Public Participation**

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. Three public meetings were organized for this purpose. The first public meeting was organized on December 9, 1999, to inform the stakeholders of TMDL development process and to obtain feedback on animal numbers in the watershed. Results of the hydrologic calibration and animal population, and fecal production estimates were discussed in the second public meeting organized on January 20, 2000. The draft TMDL report was discussed at the third public meeting held on March 28, 2000.

## **2. INTRODUCTION**

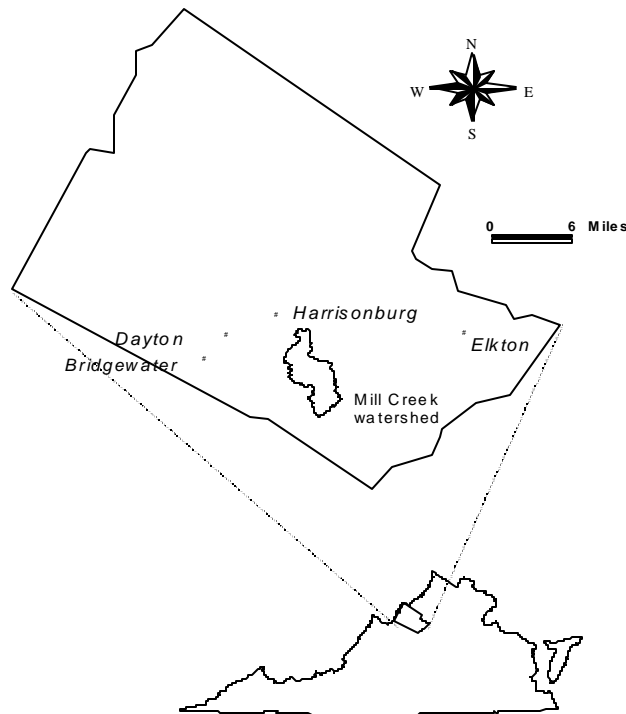
### **2.1. Background**

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to identify waterbodies that violate state water quality standards and to develop Total Daily Maximum Loads (TMDLs) for such waterbodies. A TMDL reflects the total pollutant loading a water body can receive and still meet water quality standards. A TMDL establishes the maximum allowable pollutant loading from both point and nonpoint sources for a waterbody, allocates the load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

Pollution from both point and nonpoint sources can lead to fecal coliform bacteria contamination of waterbodies. The fecal coliform bacterium is found in the intestinal tract of warm-blooded animals; consequently, fecal waste of warm-blooded animals contains fecal coliform. Even though fecal coliform is not pathogenic, its presence in water indicates the potential for contamination by fecal material. Since fecal material can contain other pathogenic organisms, waterbodies with high fecal coliform counts are likely to contain higher concentrations of pathogenic bacteria. For contact recreational uses, e.g., boating and swimming, health risk increases with fecal coliform count in the waterbody. If the fecal coliform concentration in a waterbody exceeds state water quality standards, the waterbody is listed for violation of the state fecal coliform standard for contact recreational uses. The Virginia Department of Environmental Quality (VADEQ) has identified Mill Creek as being impaired by fecal coliform for a stream length of 2.66 miles, beginning at the headwaters and continuing downstream to its confluence with North River. Mill Creek has been accorded high priority on the list for TMDL development and was targeted for completion during 1998-2000.

A constituent of the North River basin, Mill Creek watershed (Watershed ID VAV-B29R) is located in Rockingham County, Virginia, about 2.9 miles south-southeast of Harrisonburg (Figure 2.1). The watershed is situated along a north-south axis with a maximum length of 7.9 miles and a maximum width of 3.2 miles, with an area of 9,633

acres. The watershed is largely agricultural with 67% of the total watershed area occupied by cropland and pastures.



**Figure 2.1. Location of Mill Creek watershed**

Residential development, both rural and urban, currently accounts for 14% of the watershed area. Mill Creek has two important tributaries - Congers Creek and Duck Run. Mill Creek flows south and discharges into the North River, which in turn, discharges into the South Fork of the Shenandoah River (USGS Hydrologic Unit Code 02070005) about one mile to the southeast. The South Fork of the Shenandoah River is a tributary of the Potomac River; the Potomac River discharges into the Chesapeake Bay.

## **2.2. Applicable Water Quality Standards and Critical Conditions**

For a non-shellfish supporting waterbody to be in compliance with Virginia fecal coliform standards for contact recreational use, VADEQ specifies the following criteria (9 VAC 25-260-170):

1. Instantaneous criterion: Fecal coliform count shall never exceed 1,000 colony forming units (cfu) per 100 mL at any time.
2. Geometric mean criterion: The geometric mean count of fecal coliform of two or more water quality samples taken within a 30-day period shall not exceed 200 cfu/100 mL.

If the waterbody exceeds either criterion more than 10% of the time, the waterbody is classified as impaired and a TMDL must be developed and implemented to bring the waterbody into compliance with the water quality criterion. Based on the sampling frequency, only one criterion is applied to a particular datum or dataset (9 VAC 25-260-170). If the sampling frequency is one sample per 30 days or less, the instantaneous criterion is applied; for a higher sampling frequency, the geometric mean criterion is applied. For the Mill Creek watershed, the TMDL is required to meet the geometric mean criterion since the computer simulation gives daily fecal coliform concentrations, analogous to daily sample collection. The TMDL development process also must account for seasonal and annual variations in precipitation, flow, land-use, and pollutant contributions. Such an approach ensures that TMDLs, when implemented, do not result in violations under a wide variety of scenarios that affect fecal coliform loading.

### **2.3. The Water Quality Problem**

The Mill Creek watershed supports a large animal population comprised mainly of cattle and poultry; most of the animal waste generated is applied to agricultural lands. The Virginia Department of Conservation and Recreation (VADCR) has assessed this watershed as having a high potential for nonpoint source pollution from agricultural lands. Of the 64 monthly water quality samples collected by VADEQ during September 1993 through December 1998 at the outlet of the watershed, 62% of the samples exceeded the instantaneous mean criterion of 1,000 cfu/100 mL. Consequently, the impaired segment of Mill Creek was assessed as not supporting the Clean Water Act's Swimming Use Support Goal for the 1998 305(b) report and was included in the 1998 303(d) list (USEPA, 1998a, b).

## **2.4. Objective**

The objective of the project was to develop a TMDL for the Mill Creek watershed. The TMDL should account for both point and nonpoint source pollutant loadings and should incorporate a margin of safety to meet state fecal coliform standards for non-shellfish waters with respect to the geometric criterion. The following tasks were performed to achieve the project objective.

- Task 1. Identified potential fecal coliform sources, including background sources, and estimated the magnitude of each source in cooperation with stakeholders;
- Task 2. Quantified fecal coliform production from each source;
- Task 3. Simulated attenuation of fecal coliform during transport from deposited locations to water bodies;
- Task 4. Accounted for variations in precipitation, hydrology, and land-use in simulating fecal coliform deposition in streams;
- Task 5. Estimated fecal coliform concentrations in waterbodies under existing conditions;
- Task 6. Explored multiple scenarios to reduce fecal coliform concentrations to meet the geometric mean criterion;
- Task 7. Selected a TMDL that can be realistically implemented and is socially acceptable; and
- Task 8. Incorporated a margin of safety into the TMDL.

### 3. WATERSHED CHARACTERIZATION

#### 3.1. Water Resources

The largest waterbody in Mill Creek watershed is Lake Shenandoah (59.2 acres), located in the upper-third of the watershed (Figure 3.1). The lake, which is fed by two unnamed tributaries, discharges into Congers Creek. Congers Creek discharges into Mill Creek. Below the confluence of Congers Creek and Mill Creek, Duck Run discharges into Mill Creek. Excluding Lake Shenandoah, there are 14.8 miles of streams in the watershed. Mill Creek and Congers Creek are perennial streams while Duck Run can be ephemeral. The streams have trapezoidal channel cross-sections. During September 1993 through September 1996, measured discharge ranged from 86.30 cfs to 1.03 cfs, with a mean value of 9.32 cfs (VADEQ, 1997). Aquifers in this watershed are overlain by shale and limestone (VWCB, 1985). Presence of numerous solution cavities and intensive agricultural activity can result in a high potential for groundwater pollution (VWCB, 1985). Depth to water table is always greater than 6 ft in the watershed (SCS, 1985).



**Figure 3.1. Mill Creek subwatersheds and stream network**

### **3.2. Soils and Geology**

The three soil associations found in the watershed, Frederick-Lodi-Rock outcrop, Berks-Sequoia-Weikert, and Chilhowie-Edom, are characterized as follows (SCS, 1985). Frederick-Lodi-Rock outcrop (silty loam) soils are the most dominant association in the watershed, occurring both at the headwaters and at the outlet. Frederick-Lodi-Rock outcrop soils are deep and well drained with clayey subsoil and areas of rock outcrop. In upland areas, Frederick-Lodi-Rock outcrop soils are underlain by limestone and dolomite bedrock. The other two soil associations occur in the mid-region of the watershed. Chilhowie-Edom (silty clay loam) soils are moderately deep to deep and are well-drained, with a clayey subsoil; in the upland areas, these soils are underlain by limestone and interbedded shale. Berks-Sequoia-Weikert (silt loam) soils are shallow to moderately deep with loamy or clayey subsoil, underlain by shale in upland areas. All three soil associations are found on gently sloping to steep topography.

### **3.3. Climate**

The climate of the watershed was characterized based on the meteorological observations made by the National Weather Service's cooperative observer in Dale Enterprise. Dale Enterprise is located 9.4 miles north-northwest of Mill Creek. Average annual precipitation is 33.6 in. with 59% of the precipitation occurring during the crop growing season (May-October) (SERCC, 2000). Average annual snowfall is 26.5 in. with the highest snowfall occurring during February (SERCC, 2000). Average annual daily temperature is 53.3°F. The highest average daily temperature of 73.6°F occurs in July while the lowest average daily temperature of 31.0°F occurs in January (SERCC, 2000).

### **3.4. Land-use**

Using 1995 aerial photographs, VADCR identified 31 land-use types in the watershed. The land-use was verified and updated in October 1999 by Virginia Tech personnel. The 31 land-use types were consolidated into nine categories based on similarities in hydrologic and waste application/production features (Table 3.1).



**Table 3.1. Consolidation of VADCR land-use categories for Mill Creek watershed**

<b>TMDL Land-use Categories</b>	<b>Pervious/Impervious<sup>a</sup> (Percentage)</b>	<b>VADCR Land-use Categories (Class No.)</b>
Cropland	Pervious (100%)	Row Crops (2110) Gullied Row Crops (2111) Row Crops Stripped (2113) Rotational Hay (2114) Orchard (221)
Pasture 1	Pervious (100%)	Improved Pasture/Hayland (2122) Pasture (2121)
Pasture 2	Pervious (100%)	Unimproved Pasture (2123) Grazed Woodland (43)
Pasture 3	Pervious (100%)	Overgrazed Pasture (2124)
Farmstead	Pervious (72%) Impervious (28%)	Housed Poultry (2321) Farmstead (13) Farmstead with Dairy Waste Facility (813) Beef Farm (815) Large Individual Dairy Waste Facility (8)
Rural Residential	Pervious (72%) Impervious (28%)	Built-Up > 50% Porous (12) Rural Residential (14) Wooded Residential (44)
Urban Residential	Pervious (75%) Impervious (25%)	Built-Up < 50% Porous (11) Sewered Residential (16) Unclassified (999) Transitional and Disturbed Sites (7)
Loafing Lot	Pervious (100%)	Dairy Loafing Lots (2312) Unhoused Poultry (2322)
Forest	Pervious (100%)	Forest (40) Recently Harvested Woodland-Clear Cut (41) Recently Harvested Woodland-Not Clear Cut (42) Unmanaged Grass and Shrubs (3) Park, Golf course (15) Water (5) Nurseries and Christmas Tree Farms (222)

<sup>a</sup> Percent perviousness/imperviousness information was used in modeling (described in Chapter 5).

The watershed was divided into six subwatersheds to spatially analyze waste or fecal coliform distribution within the watershed (Figure 3.1). Land-use distribution in the subwatersheds and the entire Mill Creek watershed is presented in Table 3.2.

**Table 3.2. Land-use distribution in Mill Creek watershed (acres)**

Land-use	Subwatersheds						Total
	MLC-A	MLC-B	MLC-C	MLC-D	MLC-E	MLC-F	
Cropland	108.6	602.1	464.2	244.5	432.3	259.0	2,110.7
Pasture 1	177.1	909.6	1,252.3	358.1	391.0	395.2	3,483.3
Pasture 2	14.4	70.1	108.9	242.8	29.8	79.2	545.2
Pasture 3	3.4	30.9	6.3	67.0	107.5	58.1	273.2
Farmstead	2.3	54.5	62.2	25.6	41.5	18.4	204.5
Rural Residential	16.1	256.2	152.3	31.8	26.6	561.7	1,044.7
Urban Residential	1.1	2.2	4.8	0.0	17.8	479.7	505.6
Loafing Lot	0.0	0.0	0.0	9.3	0.0	0.0	9.3
Forest	31.8	213.9	321.7	78.1	72.3	738.7	1,456.5
<b>Total</b>	354.8	2,139.5	2,372.7	1,057.2	1,118.8	2,590.0	9,633.0

The watershed is mainly agricultural with pastures (44.7%) and cropland (21.9%) accounting for the largest acreages. Urban and rural residential development are important land-use categories accounting for 16% of the acreage, mainly in the upper third of the watershed. Forest is another important land-use category, accounting for 15.1% of the watershed area.

### 3.5. Potential Fecal Coliform Sources

Potential fecal coliform contributors in the watershed include a wide range of sources, such as humans, pets, livestock, and wildlife. Table 3.3 lists potential fecal coliform sources and daily fecal coliform production rates. Procedures used to calculate populations of different sources are presented in Chapter 4.

The information provided in Table 3.3 is not sufficient to draw conclusions regarding fecal coliform contributions to receiving waters. The potential for a fecal coliform source to contaminate receiving waters depends on factors such as where the waste is generated, how it is stored/handled, and how it is transported to the waterbody. For

example, even though the watershed has a sizeable human population, fecal coliform from sewerage areas and well-maintained septic systems is unlikely to reach waterbodies in large amounts.

**Table 3.3. Potential fecal coliform sources and fecal coliform production by source in Mill Creek watershed**

Potential source	Population in watershed	Fecal coliform produced ( $\times 10^6$ cfu/head-day)
Humans	3,047	1,950 <sup>a</sup>
Dairy cattle		
Milk and dry cows	230	20,000 <sup>b</sup>
Heifers <sup>c</sup>	230	9,200 <sup>d</sup>
Beef cattle	2,011	25,800 <sup>e</sup>
Pets	1,101	450 <sup>f</sup>
Poultry		
Broilers	228,000	89 <sup>g</sup>
Turkeys	112,000	93 <sup>g</sup>
Deer	284	347 <sup>h</sup>
Raccoon	13	113 <sup>h</sup>
Muskrat	277	25 <sup>h</sup>
Geese	150 (November-January) 75 (February-October)	799 <sup>f</sup>
Wood ducks	30 (September-February) <sup>i</sup> 10 (March-May) 0 (summer)	2,430 <sup>g</sup>

<sup>a</sup> Source: Geldreich et al. (1977)

<sup>b</sup> Based on data presented by Metcalf and Eddy (1979) and ASAE (1998)

<sup>c</sup> Includes calves

<sup>d</sup> Based on weight ratio of heifer to milk cow weights and fecal coliform produced by milk cow

<sup>e</sup> Based on ASAE (1998) fecal coliform production ratio of beef cattle to milk cow and fecal coliform produced by a milk cow

<sup>f</sup> Source: Weiskel et al. (1996)

<sup>g</sup> Source: ASAE (1998)

<sup>h</sup> Source: Yagow (1999)

<sup>i</sup> Two-thirds of the population is comprised of ducklings with four ducklings for every pair. It is assumed that a duckling produces one-fourth of the fecal coliform compared to an adult.

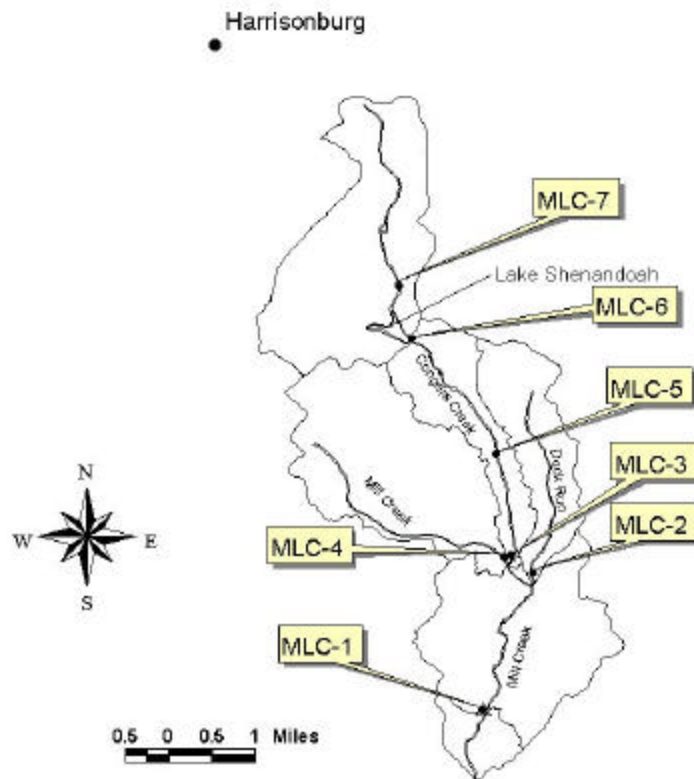
### 3.6. Flow and Water Quality Data

Virginia DEQ has been monitoring water quality in the watershed on a monthly basis beginning September 1993. In conjunction with water quality monitoring, VADEQ

conducted stream flow monitoring from September 1993 through September 1996. Stream flow data for the flow monitoring period and water quality data for the period of September 1993 through December 1998 were available for this study. Two instantaneous water quality assessments (sweeps) were also conducted by VADEQ while the TMDL development project was in progress. Simultaneous flow measurements were also made. The two studies are described in the following sections.

### 3.6.1. Historic Data

Virginia DEQ personnel monitored stream flow and pollutant concentrations at the Mill Creek watershed outlet (Station ID No. 1BMIC001.00) (Figure 3.2) on a monthly basis over three years (1993-1996) as part of a study of six watersheds in Rockingham County (VADEQ, 1997). Monthly data can be found in Table 3.4 and Figure 3.3. The study objectives were to assess stream conditions, create a database of pollutant concentrations over time, and provide baseline data and contaminant-flow relationships to assist in the development of TMDLs.



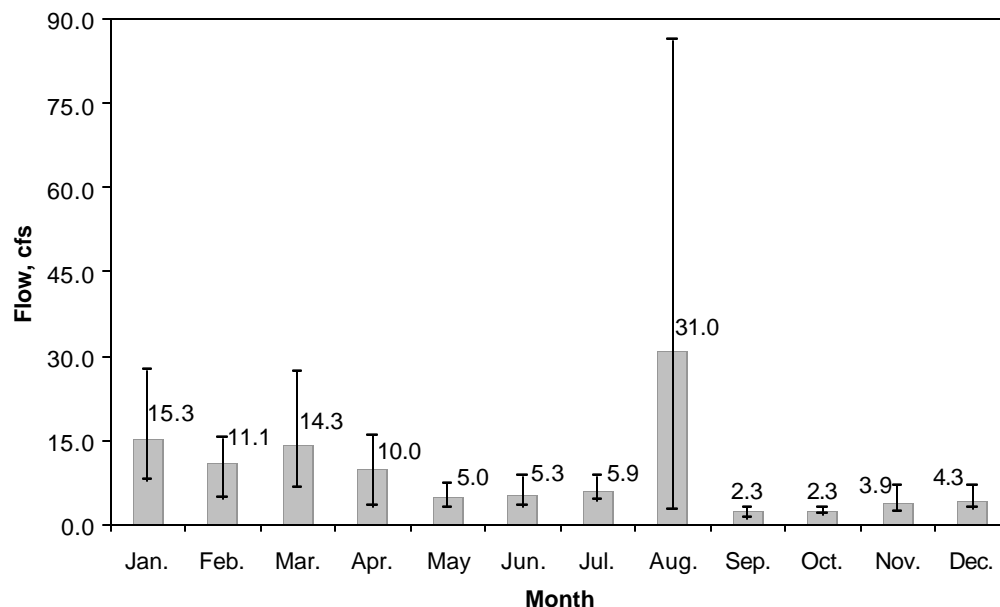
**Figure 3.2. Locations of VADEQ and sweep sites for flow measurements and water quality samples on Mill Creek**

In addition to fecal coliform, the water quality samples were analyzed for nitrate, total nitrogen, and total phosphorus. Time series data of fecal coliform concentration over the study period are shown in Figure 3.4.

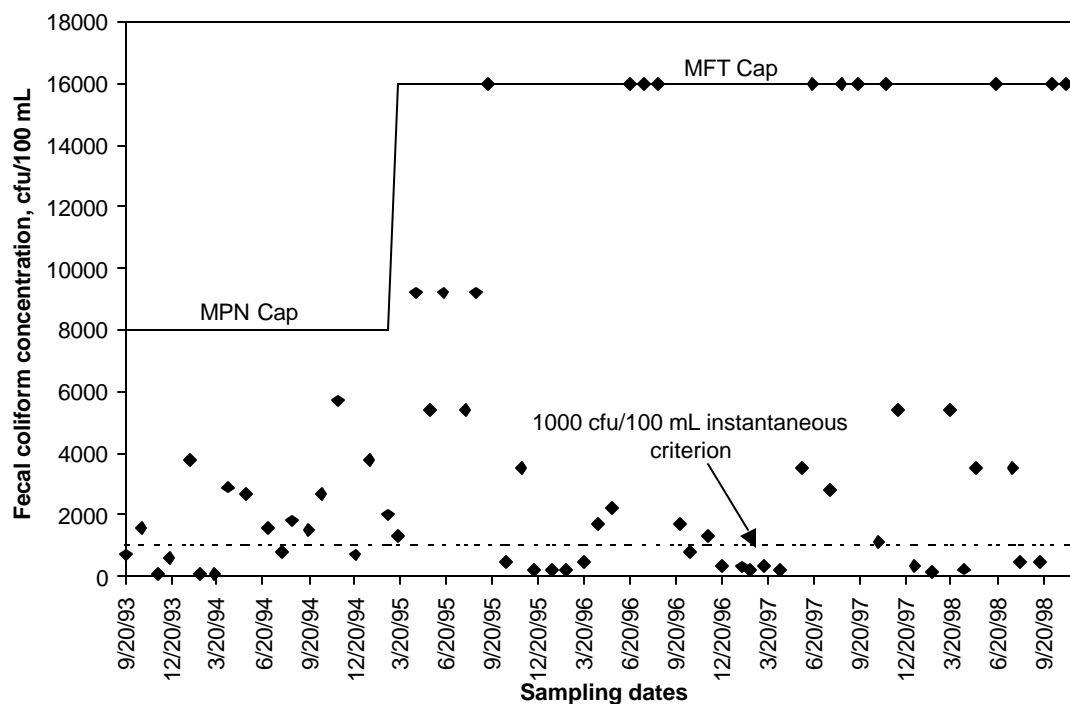
**Table 3.4. Monthly data for stream flow measured in Mill Creek for the period of September 1993 through August 1996 at the monitoring station 1BMIC001.00**

Month	Stream flow, cfs		
	Maximum <sup>a</sup>	Mean <sup>a</sup>	Minimum <sup>a</sup>
Jan.	27.5	15.3	7.8
Feb.	15.3	11.1	4.7
Mar.	27.2	14.3	6.6
Apr.	15.9	10.0	3.2
May	7.3	5.0	3.0
Jun.	8.5	5.3	3.2
Jul.	8.6	5.9	4.3
Aug.	86.3	31.0	2.7
Sep.	3.0	2.3	1.0
Oct.	3.0	2.3	1.8
Nov.	6.9	3.9	2.3
Dec.	6.9	4.3	2.8

<sup>a</sup> Based on three monthly values measured during September 1993 and August 1996



**Figure 3.3. Mean monthly stream flow in Mill Creek for the period September 1993 through August 1996 (monitoring station 1BMIC001.00). Maximum and minimum stream flow values are also indicated.**

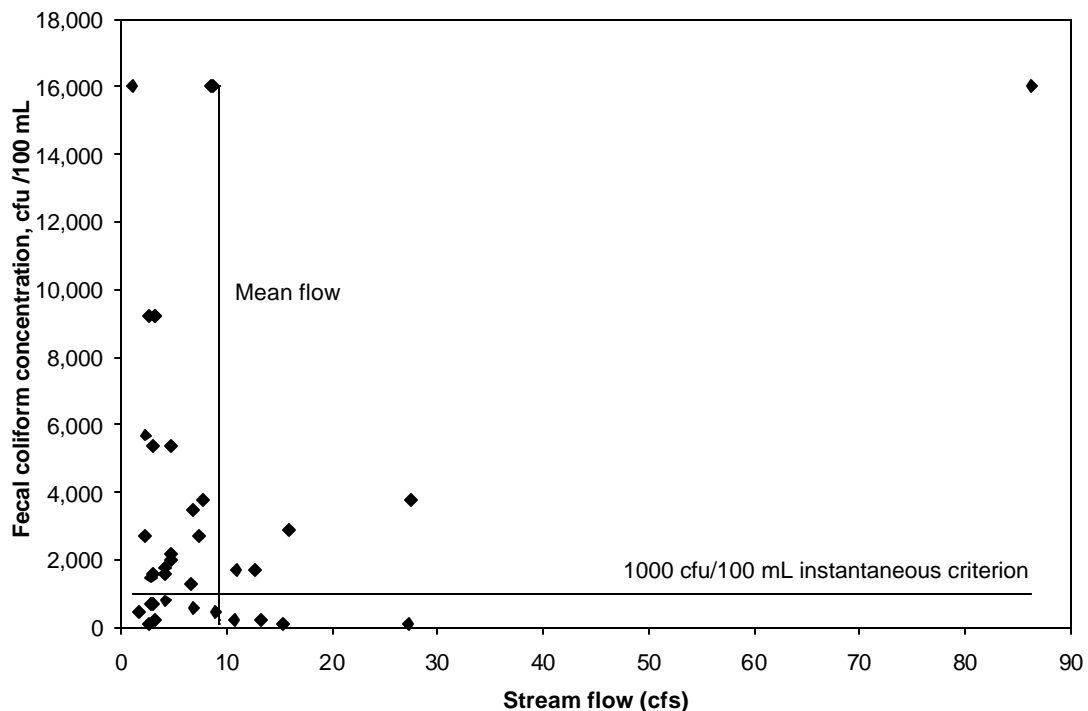


**Figure 3.4. Time series of fecal coliform concentration in Mill Creek.**

Prior to February 1995, the Most Probable Number (MPN) method was used for analyzing water samples for fecal coliform concentration. The MPN method had a maximum detection limit of 8,000 cfu/100 mL. After February 1995, the more accurate Membrane Filtration Technique (MFT) was used for the analysis of fecal coliform in water samples. The MFT has a maximum detection limit of 16,000 cfu/100 mL. The sample values shown at the maximum detection limit (Figure 3.4) indicate fecal coliform concentrations of at least 16,000 cfu/100 mL. Violations of the water quality standard were observed throughout the reporting period. However, after the spring of 1995, it was observed that water quality samples that violated the standard had higher fecal coliform concentrations than in the earlier period.

Sixty two percent of the 64 water samples collected by VADEQ during September 1993 through December 1998 contained fecal coliform concentrations in excess of the instantaneous standard of 1,000 cfu/100 mL (Figure 3.4). Seventeen percent of the samples contained the highest concentration (16,000 cfu/100 mL) of fecal coliform that could be measured by the method used. Given that water samples were collected on a monthly basis, the geometric mean criterion could not be calculated.

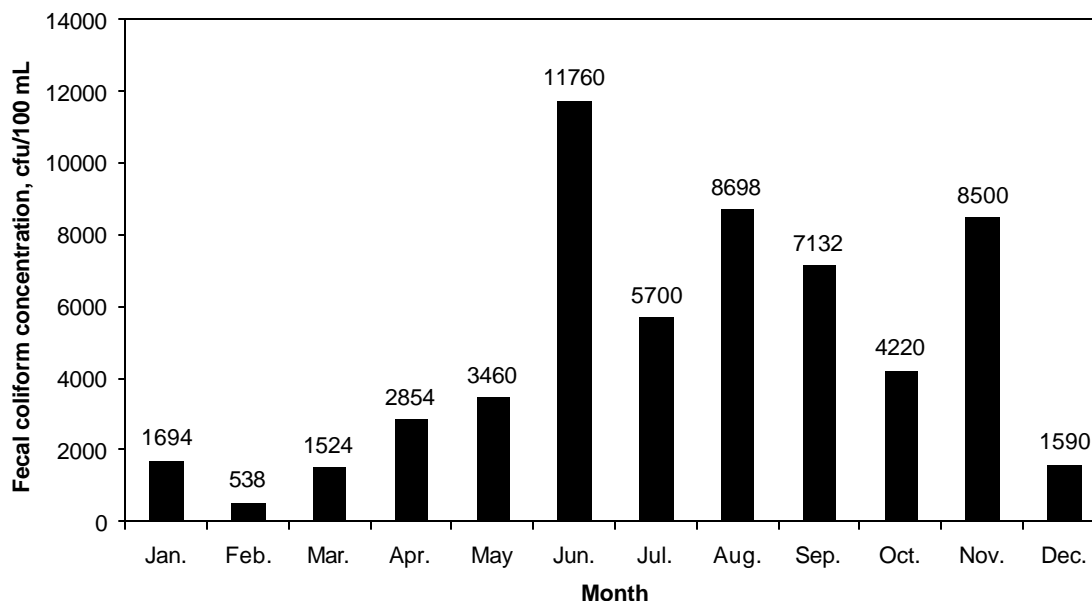
The relationship between stream flow rates and fecal coliform concentrations is shown in Figure 3.5. The stream flow rate and fecal coliform concentration data in Figure 3.5 are for the period from September 1993 through September 1996 period, when both data sets were available.



**Figure 3.5. Relationship between stream flow and fecal coliform concentration from September 1993 through September 1996.**

Based on 37 flow measurements made from September 1993 through September 1996, mean stream flow in Mill Creek was 9.32 cfs. During below average flow conditions (less than 9.32 cfs), 71.4% of all fecal coliform samples exceeded the instantaneous standard of 1,000 cfu/100 mL (Figure 3.5). Under above average flow conditions, 55.6% of the samples exceeded the instantaneous standard. However, most of the measurements were made during flow conditions that were below average. Furthermore, violations of the instantaneous standard generally involved higher fecal coliform concentrations under low-flow conditions than under high-flow conditions. Higher fecal coliform concentrations under low-flow conditions indicate the potential for direct deposition/discharge of fecal coliform in the stream.

Seasonality of fecal coliform concentration in the streams was evaluated in terms of mean monthly values (Figure 3.6). Mean monthly fecal coliform concentration was determined as the average of five monthly values over the 1994 through 1998 period.



**Figure 3.6. Impact of seasonality on fecal coliform concentrations. Average monthly fecal coliform concentration is the mean of five values over a five-year period (1994-1998).**

The data indicate seasonal variability with higher in-stream fecal coliform concentrations occurring during the summer months and lower concentrations occurring typically during the winter months. During summer (June – August), the average fecal coliform concentration was 8,719 cfu/100mL compared with 1,274 cfu/100 mL during winter (December – February). Lower fecal coliform concentrations measured during the winter and spring months (Figure 3.6) could be due to larger number of animals being in confinement during these periods, resulting in smaller fecal coliform loading to the pasture, and particularly to streams. Furthermore, land application of animal waste is limited during the winter months. Higher fecal concentrations during the summer and fall months (Figure 3.6) could be due to more cattle in streams and more animal waste is land-applied during the fall. The highest fecal coliform concentration observed during July (Figure 3.6) could also be due to a large proportion of animal waste being applied to crops during or prior to this month. Similarly, high fecal coliform concentrations observed in November (Figure 3.6) could be due to land-application of animal waste



during the fall to the winter cover crop and/or to create storage space for animal waste generated during winter. Again, it should be noted that due to the cap imposed on the fecal coliform count (8,000 or 16,000), where fecal coliform levels are equal to these maximum levels, the actual counts could be much higher, increasing the average shown in Figure 3.6.

### 3.6.2. Water quality sweep and flow measurement

The VADEQ and Virginia Tech conducted two water quality and flow monitoring sweeps, on November 30, 1999 and January 18, 2000. The purpose of the sweeps was to assess water quality conditions at various stations within the Mill Creek watershed. The following factors were considered in selecting the monitoring sites for conducting the sweep: The monitoring site should be in close proximity of a road or bridge so that the site would be located on public land with easy access; and the monitoring site should be located at the outlet of the subwatershed. Seven monitoring sites were selected that met the criteria. The sites are described in Table 3.5 and their locations are indicated in Figure 3.2.

**Table 3.5. Location and description of sampling sites for instantaneous water quality and flow assessment**

ID	Stream	Location
MLC-1 <sup>a</sup>	Mill Creek	Near watershed outlet; bridge on Rt. 671
MLC -2	Duck Run	Bridge on Rt. 708 near intersection of Rts. 708 and 676
MLC -3	Congers Creek	Bridge on Rt. 708 near intersection of Rts. 708 and 676
MLC -4	Mill Creek	Bridge on Rt. 676 near intersection of Rts. 708 and 676
MLC -5	Congers Creek	Bridge on Rt. 674 between intersection of Rts. 674 and 708 and intersection of Rts. 674 and 676
MLC -6	Congers Creek	Lake Shenandoah outlet
MLC -7	Congers Creek	Bridge on Rt. 689 near Lake View Golf Course and intersection of Rts. 689 and 687

<sup>a</sup> VADEQ sampling station for stream flow and water quality monitoring (1BMIC001.00)

Sampling began at site MLC-1, close to the watershed outlet and progressed upstream to preclude sample collection at one site from contaminating the sample at the following site. At each site, staff from VADEQ collected two water samples, one from below the stream surface and another at the bottom of the stream (after disturbing the streambed). Samples were stored on ice and were analyzed for fecal coliform using the MPN method

within 24 hours by the Virginia Department of General Services, Division of Consolidated Laboratory Services in Richmond. The MPN method used a maximum detection limit of 16,000 cfu/100 mL. The flow rates were calculated by multiplying the flow velocity (measured with a current meter) with the measured channel cross-sectional area. The results of the sweeps are presented in Table 3.6.

**Table 3.6. Results of the instantaneous fecal coliform and flow assessment in Mill Creek watershed**

ID	Stream	November 30, 1999			January 18, 2000		
		Flow (cfs)	Fecal coliform counts (cfu/100 mL)		Flow (cfs)	Fecal coliform counts (cfu/100 mL)	
			Stream surface <sup>a</sup>	Stream bottom <sup>b</sup>		Stream surface	Stream bottom
MLC -1 <sup>c</sup>	Mill Creek	1.82	16,000 <sup>d</sup>	16,000	2.54	130	700
MLC -2	Duck Run	0.05	16,000	16,000	0.00	16,000	9,200
MLC -3	Congers Creek	1.84	16,000	16,000	1.94	1,400	640
MLC -4	Mill Creek	0.02	2,200	5,400	0.15	230	490
MLC -5	Congers Creek	1.79	2,200	16,000	1.57	16,000	16,000
MLC -6	Congers Creek	1.75	93	330	1.39	18	61
MLC -7	Congers Creek	0.44	140	18 <sup>e</sup>	0.36	18	40

<sup>a</sup> Sample was obtained from just below the stream surface

<sup>b</sup> Stream bottom was stirred prior to sample collection

<sup>c</sup> VADEQ sampling station (1BMIC001.00)

<sup>d</sup> Upper limit of detection

<sup>e</sup> Lower limit of detection

#### Sweep 1 (November 30, 1999)

In the 7 days preceding the sweep, 0.41 inches of precipitation was recorded at Dale Enterprise while no precipitation was recorded in the preceding 48 hours. Fecal coliform concentrations in the water column (stream surface and bottom) exceeded the instantaneous standard at five of the seven sites. Given that the MPN method had an upper detection limit of 16,000 cfu/100 mL, actual fecal coliform concentration could have been much higher since fecal coliform concentrations at three sites were at the 16,000 cap level. Generally, fecal coliform counts were higher at the bottom of the water column indicating that there could be fecal coliform accumulation in the sediment. Fecal coliform concentrations taken near the watershed outlet were generally higher than those upstream (Table 3.6). In the upper reaches of the watershed, which is more urbanized, fecal coliform concentrations were comparatively low in the water column as

evidenced by low counts in MLC-6 and MLC-7 (Table 3.6). High fecal coliform concentrations were observed under low-flow conditions in the sweep as well as in the VADEQ (1997) study.

#### Sweep 2 (January 18, 2000)

In the 7 days preceding the sweep, 0.30 inches of precipitation was recorded at Dale Enterprise while no precipitation was recorded in the preceding 48 hours. Fecal coliform concentration in the stream surface exceeded the instantaneous standard at three of seven locations. Two samples at the stream bottom exceeded the instantaneous standard. Of the five samples that violated the instantaneous standard, three samples had 16,000 cfu/100 mL. As in the first sweep, low fecal coliform concentrations in the upper reaches of the watershed indicated relatively lower fecal coliform loading from urbanized areas than from agricultural areas located downstream.

Compared to the first sweep, fecal coliform concentrations were generally lower in both the stream surface and bottom water samples in the second sweep. Lower fecal coliform counts in the second sweep (January 2000) compared to the first sweep (November 1999) was supported by the historic data (Figure 3.6). As compared to the first sweep, lower fecal coliform counts in the second sweep could be due to fewer animals in the stream during the winter months resulting in less direct deposition of fecal coliform in the stream.

## **4. SOURCE ASSESSMENT OF FECAL COLIFORM**

Potential fecal coliform sources in Mill Creek watershed were assessed using multiple approaches, including information from VADEQ, VADCR, Virginia Department of Game and Inland Fisheries (VADGIF), Virginia Cooperative Extension (VCE), public participation, watershed reconnaissance and monitoring, published information, and professional judgment. There are no permitted point sources of fecal coliform in the Mill Creek watershed. Potential nonpoint sources of fecal coliform are described in detail in the following sections.

### **4.1. Humans and Pets**

Mill Creek watershed has a population of 3,047 people (1999 estimate). Fecal coliform from humans can be transported to streams from failing septic systems or via straight pipes discharging directly into streams.

#### **4.1.1. Failing Septic Systems**

Septic system failure is manifested by the rise of effluent to the soil surface. Runoff can transport the effluent on the surface containing fecal coliform to receiving waters. County maps were used to identify sewered service areas in the watershed, which were classified as the urban residential land-use. There were 500 houses connected to the sewer system, in subwatersheds MLC-E and MLC-F (Figure 3.1). Locations of the 601 unsewered households (with septic systems) were identified using 1999 E-911 digital data (see Glossary) (Rockingham Co. Planning Dept., 1999), and assigned to the rural residential land-use. Each unsewered household was classified into one of three age categories (pre-1964, 1964-1984, and post-1984) based on USGS 7.5-min. topographic maps which were initially created using 1964 photographs and were photo-revised in 1984. Professional judgment (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, Va.) was applied in assuming that septic system failure rates for houses in the pre-1964, 1964-1984, and post-1984 age categories were 40, 20, and 5%, respectively. Estimates of these failure rates were also supported by the Holmans Creek Watershed Study (a watershed just north of the study area and Linville Creek), which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (Bankson, 2000).

Daily total fecal coliform load to the land from a failing septic system was determined by multiplying the average occupancy rate for the watershed (2.69 persons, 1990 Census) by the per capita fecal coliform production rate of  $1.95 \times 10^9$  cfu/day (Geldreich et al., 1977). Hence, the total fecal coliform loading to the land from a failing septic system was  $5.25 \times 10^9$  cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur. The number of failing septic systems in the watershed is given in Table 4.1.

**Table 4.1. Estimated number of unsewered houses in each age category, number of failing septic systems, and pet population in Mill Creek watershed**

Subwatershed	Unsewered houses in each age category (no.)			Failing septic systems (no.)	Pet population <sup>a</sup>
	Pre-1964	1964-1984	Post-1984		
MLC-A	5	5	8	3	18
MLC-B	46	64	33	33	143
MLC-C	73	32	25	37	130
MLC-D	20	6	4	9	30
MLC-E	16	10	11	9	55
MLC-F	79	88	76	53	725
<b>Total</b>	<b>239</b>	<b>205</b>	<b>157</b>	<b>144</b>	<b>1,101</b>

<sup>a</sup> Assumed an average of one pet per household

#### **4.1.2. Straight Pipes**

Ten percent and 2% of the houses within 150 ft of streams, in the pre-1964 and 1964-1984 age categories, respectively, were assumed to have straight pipes (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, Va.). Based on these criteria, there are no known straight pipes in the watershed.

#### **4.1.3. Pets**

Assuming one pet per household, there are 1,101 pets in Mill Creek watershed. A pet produces  $0.45 \times 10^9$  cfu/day (Geldreich et al., 1977). Pet waste is generated in the rural residential and urban residential land-use types. Fecal coliform loading to streams from pet waste can result from surface runoff transporting fecal coliform from residential areas.

## 4.2. Cattle

Fecal coliform in cattle waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animal waste deposited on pastures or applied to crop and hay land.

### 4.2.1. Distribution of Dairy and Beef Cattle in the Mill Creek watershed

There are four dairy farms in the watershed, two of which are on the watershed boundary. Based on discussion with local producers, the total number of milk and dry cows was estimated at 230. The replacement herd of heifers and calves was estimated to be 100% of the dairy herd (Virginia Cooperative Extension (VCE)) resulting in a total of 460 dairy cattle for the watershed (Table 3.3); this total was assigned to the appropriate subwatershed based on the location of the dairies (Table 4.2). Based on discussion with VCE personnel, of the dairy cattle population in the watershed, 42% of the cattle are milk cows, 8% are dry cows, and 50% are heifers. Number of dairy operations with attached loafing lots for each subwatershed is shown in Table 4.2.

**Table 4.2. Distribution of dairy cattle, dairy operations, loafing lots, and beef cattle between subwatersheds**

Subwatershed	Dairy cattle	No. of dairy operations	No. of dairy operations with attached loafing lots	Beef cattle
MLC-A	0	0	0	85
MLC-B	260	1	0	371
MLC-C	0	0	0	783
MLC-D	90	1	1	380
MLC-E	110	2	0	295
MLC-F	0	0	0	97
<b>Total</b>	<b>460</b>	<b>4</b>	<b>1</b>	<b>2,011</b>

Beef cattle in the watershed included cow/calf and feeder operations. The beef cattle population (2,011) was estimated for the watershed based on local knowledge. The following procedure was used to estimate beef population by subwatershed (Table 4.2).

1. Based on local knowledge of the watershed, it was assumed that Pastures 1, 2, and 3 had stocking ratios of 1, 2, and 4, respectively, i.e. pasture 2 was stocked with twice the number of animals per acre than pasture 1. Similarly, it was assumed that Pasture 3 was stocked with four times the number of cattle per acre than Pasture 1.

Accordingly, relative stocking densities (RSDs) for Pastures 1, 2, and 3 were 0.14 (1/7), 0.29 (2/7), and 0.57 (4/7), respectively.

2. Fraction of beef cattle in each pasture category was calculated as follows.

Fraction of beef cattle in Pasture 1 =

$$(P_1 \times RSD_1) / ((P_1 \times RSD_1) + (P_2 \times RSD_2) + (P_3 \times RSD_3)) \quad [4.1a]$$

Fraction of beef cattle in Pasture 2 =

$$(P_2 \times RSD_2) / ((P_1 \times RSD_1) + (P_2 \times RSD_2) + (P_3 \times RSD_3)) \quad [4.1b]$$

Fraction of beef cattle in Pasture 3 =

$$(P_3 \times RSD_3) / ((P_1 \times RSD_1) + (P_2 \times RSD_2) + (P_3 \times RSD_3)) \quad [4.1c]$$

where  $P_1$ ,  $P_2$ , and  $P_3$  = acreages under Pastures 1, 2, and 3, respectively. As mentioned earlier,  $RSD_1=0.14$ ,  $RSD_2=0.29$ , and  $RSD_3=0.57$  are relative stocking densities in Pastures 1, 2, and 3, respectively.

3. Number of beef cattle in each pasture category was calculated by multiplying the acreage by the fraction of beef cattle in that category. Stocking density for each pasture category was obtained by dividing the number of beef cattle in that pasture category by the acreage. Beef cattle stocking densities for pastures 1, 2, and 3, were 0.36, 0.71, and 1.42 beef cattle/ac, respectively.
4. For each subwatershed, pasture 1 acreage was multiplied by pasture 1 stocking density to calculate number of beef cattle in pasture 1. Similarly, beef cattle numbers were calculated for pastures 2 and 3. Beef cattle population in the subwatershed was obtained by summing the cattle population for all three pasture categories.

Depending on the time of year and type of cattle (i.e., milk cow versus heifer), cattle spend varying amounts of time in different land-use types (i.e., confinement versus pasture). Accordingly, the proportion of fecal coliform deposited in any given land area varies throughout the year. Based on discussions with VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle, and, thus, their manure among different land-use types and in the stream.

- (a) Cattle are confined according to the schedule given in Table 4.3.
- (b) When the milk cows are not confined, they spend 25% of the time in the loafing lot and 75% of the time on pasture. However, if a dairy operation does not have an adjacent loafing lot, it is assumed that the milk cows spend all of their unconfined

hours in the pastures. All other dairy and beef cattle are on pastures when not in confinement.

**Table 4.3. Time spent by cattle in confinement and in the stream**

Month	Time spent in confinement (%)		Time spent in the stream (hours/day) <sup>a</sup>
	Milk cows	Dry cows, heifers, and beef cattle	
January	75%	40%	0.50
February	75%	40%	0.50
March	40%	0%	0.50
April	30%	0%	0.75
May	30%	0%	1.00
June	30%	0%	3.50
July	30%	0%	3.50
August	30%	0%	3.50
September	30%	0%	1.00
October	30%	0%	0.75
November	40%	0%	0.50
December	75%	40%	0.50

<sup>a</sup> Time spent in and around the stream by cows that have stream access

- (c) Pasture 2 (unimproved pasture/grazed woodlands) stocks twice as many cattle per unit area as pasture 1 (improved pasture/hayland). Pasture 3 (overgrazed pasture) stocks four times as many cattle per unit area as pasture 1.
- (d) Cattle on pastures that are contiguous to streams (1,265 acres for all pasture categories) (Table 4.4), have stream access.

**Table 4.4. Pasture acreages contiguous to stream**

Subwatershed	Pasture 1		Pasture 2		Pasture 3	
	Acres	% <sup>a</sup>	Acres	%	Acres	%
MLC-A	105.1	59.3	6.0	41.9	0.0	0.0
MLC-B	177.4	19.5	53.8	77.1	0.0	0.0
MLC-C	166.6	13.3	0.0	0.0	0.0	0.0
MLC-D	102.4	28.6	238.0	97.9	28.3	42.3
MLC-E	311.2	79.6	0.0	0.0	75.9	70.8
MLC-F	0.0	0.0	0.0	0.0	0.0	0.0
<b>Total</b>	<b>862.7</b>	<b>24.8</b>	<b>297.8</b>	<b>54.6</b>	<b>104.2</b>	<b>38.1</b>

<sup>a</sup> Percent of pasture area contiguous to stream to the total pasture area of that type in that subwatershed



- (e) Cattle with stream access spend varying amounts of time in the stream during different seasons (Table 4.3). Cattle spend more time in the stream during the three summer months, among other things to protect their hooves from hornflies.
- (f) Thirty percent of cattle in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the manure is deposited in pastures.

A sample calculation for determining the dairy cattle numbers to different land-use types and stream in subwatershed MLC-A is shown in Appendix A. The resulting numbers of cattle in each land-use type as well as in the stream for all subwatersheds are given in Table 4.5 for dairy cattle and in Table 4.6 for beef cattle.

**Table 4.5. Distribution of the dairy cattle<sup>a</sup> population**

Months	Confined	Loafing lot	Pasture			Stream <sup>b</sup>	Total
			1	2	3		
January	252	3	125	40	40	0	460
February	252	3	125	40	40	0	460
March	77	7	229	73	73	1	460
April	58	8	240	76	76	2	460
May	58	9	239	76	76	2	460
June	58	9	237	75	75	6	460
July	58	9	237	75	75	6	460
August	58	9	237	75	75	6	460
September	58	9	239	76	76	2	460
October	58	8	240	76	76	2	460
November	77	7	229	73	73	1	460
December	252	3	125	40	40	0	460

<sup>a</sup> Includes milk cows, dry cows, and heifers

<sup>b</sup> No. of dairy cattle defecating in stream

**Table 4.6. Distribution of the beef cattle population**

Months	Confined	Loafing lot	Pasture			Stream <sup>a</sup>	Total
			1	2	3		
January	804	0	737	234	234	2	2,011
February	804	0	737	234	234	2	2,011
March	0	0	1,227	389	389	6	2,011
April	0	0	1,226	388	388	9	2,011
May	0	0	1,223	388	388	12	2,011
June	0	0	1,213	384	384	30	2,011
July	0	0	1,213	384	384	30	2,011
August	0	0	1,213	384	384	30	2,011
September	0	0	1,223	388	388	12	2,011
October	0	0	1,226	388	388	9	2,011
November	0	0	1,227	389	389	6	2,011
December	804	0	737	234	234	2	2,011

<sup>a</sup> No. of beef cattle defecating in stream

#### **4.2.2. Direct Manure Deposition in Streams**

Direct manure loading to streams is due to both dairy (Table 4.5) and beef cattle (Table 4.6) defecating in the stream. However, only cattle on pastures contiguous to streams have stream access. Manure loading to streams was calculated from the number and type of cattle in the stream and the waste produced by each type of cattle for each subwatershed. Manure loading increases during the warmer months when cattle spend more time in water compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the watershed is 354,233 lb. Daily fecal coliform loading due to cows depositing in the stream, averaged over the year, is  $363.6 \times 10^9$  cfu. Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that mainly dissolved fecal coliform bacteria are transported with the flow. Sediment-bound fecal coliform bacteria are likely to be resuspended and transported to the watershed outlet under high flow conditions. Die-off of fecal coliform in the stream depends on sunlight, predation, turbidity, and other environmental factors.

#### **4.2.3. Direct Manure Deposition on Pastures**

Fecal loading on pastures is contributed by dairy and beef cattle that graze on pastures but do not deposit in streams (Tables 4.5 and 4.6). Manure loading on pasture was estimated by multiplying the total number of each type of cattle (milk cow, dry cow, heifer, and beef) by the amount of manure it produced per day. The total amount of

manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement schedule of the cattle changes with season, manure and fecal coliform loading on pasture also changes with season.

Pasture 1, pasture 2, and pasture 3 have average annual manure loadings of 8,510, 17,021, and 34,041 lb/ac, respectively. The loadings vary because stocking density varies with pasture type. Fecal coliform loadings on a daily basis averaged over the year are  $9.0 \times 10^9$ ,  $18.0 \times 10^9$ , and  $36.0 \times 10^9$  cfu/ac for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

#### **4.2.4. Solid Manure Loading in the Loafing Lot**

In dairies with loafing lots, milk cows spend 25% of the time in loafing lots when not confined (Table 4.3); milk cows spend the remaining 75% of time in pastures. If a dairy farm does not have an attached loafing lot, the milk cows spend all their unconfined hours on the pasture. It is assumed that other cattle do not spend time on the loafing lot. Total fecal coliform loading on loafing lots was calculated by multiplying the number of milk cows (Table 4.5) in the loafing lot by the total fecal coliform produced per cow each day. Average annual manure loading to the loafing lot is 24,414 lb/ac. Daily fecal coliform loading to the loafing lot is  $107.9 \times 10^9$  cfu/ac. Fecal coliform bacteria accumulated on loafing lots are subject to die-off due to desiccation and UV radiation. Runoff may transport some portion of the remaining fecal coliform to receiving waters.

#### **4.2.5. Land Application of Liquid Dairy Manure**

A typical milk cow weighs 1,400 lb and produces 17 gallons of liquid manure/day (ASAE, 1998). Based on the monthly confinement schedule (Table 4.3) and the number of milk cows (Section 4.2.1), annual liquid dairy manure production in the watershed is 0.6 million gallons. Based on per capita fecal coliform production of milk cows, fresh liquid dairy manure contains  $1.18 \times 10^9$  cfu/gal. It was assumed that all liquid dairy manure produced in a subwatershed was applied within the subwatershed. Liquid dairy manure application rates are 6,600 and 3,900 gal/ac-year to cropland and pasture 1 land-use

categories (VADCR, 1999), respectively, with cropland receiving priority in application. Based on availability of land and liquid dairy manure, as well as the assumptions regarding application rates and priority of application, liquid dairy manure was applied to 50.7 acres (2.4%) and 99.1 acres (2.9%) of cropland and pasture 1, respectively. Since there was insufficient liquid dairy manure for cropland and pasture 1, liquid dairy manure was not applied to pasture 2 or pasture 3.

The typical crop rotation in the watershed is a seven-year rotation with three years of corn-rye and four years of rotational hay (VADCR, 1999). It was assumed that 50% of the corn acreage was under no-till cultivation. Liquid manure is applied to cropland during February through May (prior to planting) and in October-November (after the crops are harvested). For spring application to cropland, liquid manure is applied on the soil surface to rotational hay and no-till corn, and is incorporated into the soil for corn in conventional tillage. In fall, liquid manure is incorporated into the soil for cropland under rye, and surface-applied to cropland under rotational hay. During June through September, liquid manure is surface-applied to pasture 1. It was assumed that only 10% of the subsurface-applied fecal coliform were available for removal in surface runoff based on local knowledge. The application schedule of liquid manure (VADCR, 1999) is given in Table 4.7. Dry cows and heifers were assumed to produce only solid manure.

**Table 4.7. Schedule of cattle and poultry waste application**

<b>Month</b>	<b>Liquid manure applied (%)<sup>a</sup></b>	<b>Solid manure or poultry litter applied (%)<sup>a</sup></b>
<b>January</b>	0	0
<b>February</b>	5	5
<b>March</b>	25	25
<b>April</b>	20	20
<b>May</b>	5	5
<b>June</b>	10	5
<b>July</b>	0	5
<b>August</b>	5	5
<b>September</b>	15	10
<b>October</b>	5	10
<b>November</b>	10	10
<b>December</b>	0	0

<sup>a</sup> As percent of annual production

#### 4.2.6. Land Application of Solid Manure

Solid manure produced by dry cows, heifers, and beef cattle during confinement is collected for land application. It was assumed that milk cows produce only liquid manure while in confinement. The number of cattle, their typical weights, amounts of solid manure produced, and fecal coliform concentration in fresh manure are given in Table 4.8. As in the case of liquid manure, it was assumed that all solid manure produced within a subwatershed is applied to that subwatershed. Amount of solid manure produced in each subwatershed was estimated based on the populations of dry cows, heifers, and beef cattle in the subwatershed (Table 4.2) and their confinement schedules (Table 4.3). Solid manure from dry cows, heifers, and beef cattle contained different fecal coliform concentrations (cfu/lb) (Table 4.8). Hence, a weighted average fecal coliform concentration in solid manure was calculated based on the relative manure contribution from dry cows, heifers, and beef cattle (Table 4.8). Dry cows and heifers account for 8 and 50%, respectively, of the total dairy cattle population.

**Table 4.8. Estimated population of dry cows, heifers, and beef cattle, typical weights, per capita solid manure production, fecal coliform concentration in fresh solid manure in individual cattle type, and weighted average fecal coliform concentration in fresh solid manure.**

Type of cattle	Population	Typical weight (lb)	Solid manure produced (lb/animal-day)	Fecal coliform concentration in fresh manure ( $\times 10^6$ cfu/lb)	Weighted average fecal coliform concentration in fresh manure ( $\times 10^6$ cfu/lb)
Dry cow	37	1,400 <sup>a</sup>	115.0 <sup>b</sup>	174 <sup>c</sup>	408
Heifer	230	640 <sup>d</sup>	40.7 <sup>a</sup>	226 <sup>c</sup>	
Beef	2,011	1,000 <sup>e</sup>	60.0 <sup>f</sup>	430 <sup>c</sup>	

<sup>a</sup> Source: ASAE (1998)

<sup>b</sup> Source: VADCR (1995)

<sup>c</sup> Based on per capita fecal coliform production per day (Table 3.3) and manure production

<sup>d</sup> Based on weighted average weight assuming that 57% of the animals are older than 10 months (900 lb ea.), 28% are 1.5-10 months (400 lb ea.) and the remainder are less than 1.5 months (110 lb ea.) (MWPS, 1993).

<sup>e</sup> Based on discussion with local producers

<sup>f</sup> Source: MWPS (1993)

Solid manure is applied at the rate of 12 tons/ac-year to both cropland and pasture 1, with priority given to cropland. As in the case of liquid manure, solid manure is only

applied to cropland during February through May, October, and November. During June through September, all solid manure is applied to pasture 1. The method of application of solid manure to cropland or pasture 1 is assumed to be identical to the method of application of liquid dairy manure. The application schedule for solid manure is given in Table 4.7. Based on availability of land and solid manure, as well as the assumptions regarding application rates and priority of application, solid manure was applied to 101.4 acres (4.8%) and 51.4 acres (1.5%) of the cropland and pasture 1, respectively. Since there was insufficient solid manure for cropland and pasture 1, solid manure was not applied to pasture 2 or pasture 3.

#### **4.3. Poultry**

The poultry population (Table 3.3) was estimated based on discussions with local producers and nutrient management specialists. Poultry population numbers thus obtained were found to compare well with poultry housing capacity. Poultry housing capacity was estimated using 1999 E-911 data (length of houses) (Rockingham Co. Planning Dept., 1999) while house widths and space required per bird were determined through discussions with local producers and processors. Poultry litter production was estimated from the poultry population after accounting for the time when the houses are not occupied (Table 4.9.). It is not known which poultry litter (layer or broiler or turkey) is applied to a land-use. Hence, a weighted average fecal coliform concentration was estimated for poultry litter based on relative proportions of litter from all poultry types and their respective fecal coliform contents (Table 4.9).

Since poultry is raised entirely in confinement, all litter produced is collected and stored prior to land application. Poultry litter is applied at 3 tons/ac-year to cropland first, the remaining litter being applied to pasture 1. After application to cropland and pasture 1, the remaining litter is applied to pastures 2 and 3 at 1.5 tons/ac-year, in order of priority. Method of poultry litter application to cropland and pastures is assumed to be identical to the method of cattle manure application.

**Table 4.9. Estimated daily litter production, litter fecal coliform content for individual poultry types, and weighted average fecal coliform content**

Poultry Type	Typical Weight (lb) <sup>a</sup>	Production cycles (per year) <sup>b</sup>	Occupancy factor <sup>c</sup>	Litter produced per bird		Fecal coliform content (×10 <sup>9</sup> cfu/lb) <sup>f</sup>	Weighted average fecal coliform content (×10 <sup>9</sup> cfu/lb)
				(lb/cycle) <sup>d</sup>	(lb/day) <sup>e</sup>		
Broiler	2	6	0.79	2.6	0.04	1.65	0.84
Turkey	15	5	0.87	18.0	0.25	0.33	

<sup>a</sup> Source: ASAE (1998)

<sup>b</sup> Based on information from VADCR and producers

<sup>c</sup> Fraction of time when the poultry house is occupied; broiler – 48 days/61 days; turkey (5 cycles) – 45 weeks/52 weeks

<sup>d</sup> Source: VADCR (1999)

<sup>e</sup> Litter produced per bird per day is equal to the product of production cycles per year and litter produced per cycle divided by number of days in a year.

<sup>f</sup> Fecal content in litter is equal to fecal coliform produced per day per bird (Table 3.3) multiplied by the occupancy factor, divided by the litter produced per day per bird.

Application schedule of poultry litter is given in Table 4.7. As with liquid and solid manures, poultry litter is not applied to cropland during June through September. Based on availability of land and poultry litter, as well as the assumptions regarding application rates and priority of application, poultry litter was applied to 618.2 acres (39.6%) and 294.9 acres (20.0%) of cropland and pasture 1, respectively. Pastures 2 and 3 did not receive any poultry litter since there was insufficient poultry litter to apply to the entire cropland and pasture 1 acreages.

Given that poultry litter is lighter to transport than cattle manure, poultry litter produced within the watershed was assumed to be applied throughout the watershed irrespective of the subwatershed in which it is produced. Since there is sufficient acreage of appropriate land-uses within the watershed for land application, no poultry litter is exported from the watershed. Poultry litter was allocated to subwatersheds as a fraction of the total amount produced within the watershed as follows:

$$PL_i = \frac{((CL_i + P1_i) \times AF_1) + ((P2_i + P3_i) \times AF_2)}{\sum_{i=1}^N \{((CL_i + P1_i) \times AF_1) + ((P2_i + P3_i) \times AF_2)\}} \quad [4.2]$$

where,

N = number of subwatersheds in the watershed (6);

CL<sub>i</sub> = Cropland acreage in subwatershed i;

- $P1_i$  = Pasture 1 acreage in subwatershed  $i$ ;  
 $P2_i$  = Pasture 2 acreage in subwatershed  $i$ ;  
 $P3_i$  = Pasture 3 acreage in subwatershed  $i$ ;  
 $AF_1$  = Application factor, considered one for cropland and pasture 1; and  
 $AF_2$  = Application factor, considered 1/2 for pastures 2 and 3 that have one-half application rate as compared to cropland and pasture 1.

Using Equation [4.2], poultry litter amounts were assigned to individual subwatersheds as percent of total poultry litter produced within the watershed (Table 4.10).

**Table 4.10. Distribution of poultry litter between the subwatersheds**

Subwatershed	Poultry litter (%) <sup>a</sup>
MLC-A	5
MLC-B	26
MLC-C	30
MLC-D	12
MLC-E	15
MLC-F	12
<b>Total</b>	100

<sup>a</sup> Percent of total assigned to (but not necessarily produced in) the subwatershed

#### 4.4. Wildlife

Wildlife fecal coliform contributions can be from excretion of waste on land and from excretion directly into streams. Extensive watershed reconnaissance was undertaken to identify different species of wildlife, determine population numbers, and assess habitat in the watershed to support and supplement information provided by VADGIF. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, goose, and wood duck. Population numbers for each species and fecal coliform amounts were determined (Table 3.3) along with preferred habitat and habitat area (Table 4.11).

Professional judgment was used in estimating the percent of each wildlife species depositing directly into streams based upon habitat (Table 4.11). Fecal matter produced by deer that is not directly deposited in streams, is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their



waste in streams and pastures. Geese deposit their waste in streams, lakes, and pastures, while ducks deposit their waste in streams and forests.

**Table 4.11. Wildlife habitat description and acreage, and percent direct fecal deposition in streams.**

<b>Wildlife type</b>	<b>Habitat</b>	<b>Acres of habitat</b>	<b>Percent direct fecal deposition in streams</b>
<b>Deer</b>	Forested areas and adjacent pastures with continuous water supply	7,560	1
<b>Raccoon</b>	Forested areas within ½ mile on either side of stream	550	10
<b>Muskrat</b>	150 ft on either side of stream	277	25
<b>Geese</b>	All surface water bodies plus a 325-ft wide buffer around such water bodies	124	25
<b>Duck</b>	¼ mile on either side of stream	250	25

Fecal loading from wildlife was estimated for each subwatershed. A deer population of 284 animals was estimated using a density of 24 deer/mi.<sup>2</sup> of watershed area (VADGIF). The deer population was distributed among the subwatersheds based on pasture and forest acreage in the subwatershed as a fraction of pasture plus forest area in the entire watershed. The raccoon population (13 animals) was estimated using a density of 15 raccoons/mi.<sup>2</sup> (VADGIF). Raccoons were distributed among the subwatersheds based on the forest acreages. A low density of one muskrat/ac of habitat was assumed in view of very little evidence of muskrat activity. The muskrat population was distributed among the subwatersheds based on their acreages of suitable habitat (Table 4.12); however, no muskrats were assigned to subwatersheds MLC-C and MLC-E since the streams in these subwatersheds are ephemeral. A resident population of 75 geese was observed in Lake Shenandoah in early fall. During November through January, the geese population doubled due to an influx of migratory birds. Assuming a density of two wood ducks/50 acres of habitat during March through May (spring), a wood duck population of 10 ducks was estimated. During September through February (fall - winter), the wood duck population triples due to the presence of ducklings. During June through August (summer), there are no wood ducks in the watershed. The wood duck population was distributed among the subwatersheds based on their acreages of suitable habitat (Table 4.12). Distribution of wildlife among subwatersheds is given in Table 4.12.

**Table 4.12. Distribution of wildlife among subwatersheds**

Subwatershed	Wildlife numbers				
	Deer	Raccoon	Muskrat	Geese <sup>a</sup>	Wood ducks <sup>b</sup>
<b>MLC-A</b>	12	0	35	0/0	0/0/0
<b>MLC-B</b>	65	0	66	0/0	0/0/0
<b>MLC-C</b>	86	5	0	0/0	12/4/0
<b>MLC-D</b>	38	2	117	0/0	6/2/0
<b>MLC-E</b>	32	4	0	0/0	6/2/0
<b>MLC-F</b>	51	2	59	150/75	6/2/0
<b>Total</b>	284	13	277	150/75	30/10/0

<sup>a</sup> Population during November - January/population during February - October

<sup>b</sup> Population during September – February/population during March – May/population during June – August, respectively

#### 4.5. Summary: Contribution from All Sources

Monthly fecal coliform deposition and percent breakdown in different locations in the watershed is given in Table 4.13. It should be noted that Table 4.13 does not reflect either storage losses of fecal coliform collected in confined animal structures or the distribution of fecal coliform to cropland and pasture from land application of manure.

For periods in confinement, Table 4.13 presents information on waste produced by confined cattle and poultry which is collected for storage. For the periods not in confinement, Table 4.13 shows cattle manure distributed to pasture with small fractions going to loafing lot or directly into streams. Failing septic systems and pet waste contribute to fecal coliform loads in the rural residential and farmstead categories. Pets in urban residential areas contribute to the fecal coliform load for that land-use. Wildlife contribute fecal coliform directly to stream, to pastures and forests.

It is clear from Table 4.13 that 96% of the fecal coliform is produced in confinement and on pastures. Since waste produced in confinement is eventually applied to cropland and pastures, it could be prematurely assumed that 96% of fecal coliform loading in streams originates from croplands and pastures. However, in addition to fecal coliform production, die-off of fecal coliform and transport of fecal coliform to receiving waters have to be considered in estimating fecal coliform loads in streams. Fecal coliform die-off can occur in storage with die-off rates varying with storage conditions. Fecal coliform die-off on land depends on environmental factors, type of fecal coliform source (e.g.,

poultry waste versus liquid manure), and application method (e.g., incorporation versus surface broadcast). Finally, soil (e.g., soil texture), environmental (e.g., intensity of precipitation), geographic (e.g., distance to stream), and cultural (e.g., waste application method) factors will also affect how much of the applied fecal coliform reaches the waterbody. All three factors were considered in estimating fecal coliform loads to receiving waters as described in Chapter 5.

**Table 4.13. Monthly fecal coliform deposition in different locations in the Mill Creek watershed**

Month	Confinement		Pasture 1 <sup>a</sup>		Pasture 2 <sup>a</sup>		Pasture 3 <sup>a</sup>		Rural Residential <sup>b</sup>		Farmstead <sup>c</sup>		Urban Residential		Loafing lot		Forest		Stream <sup>d</sup>		Total <sup>e</sup> ( $\times 10^{12}$ cfu)
	$\times 10^{12}$ cfu	%	$\times 10^{12}$ cfu	%	$\times 10^{12}$ cfu	%	$\times 10^{12}$ cfu	%	$\times 10^{12}$ cfu	%	$\times 10^{12}$ cfu	%	$\times 10^{12}$ cfu	%	$\times 10^{12}$ cfu	%	$\times 10^{12}$ cfu	%	$\times 10^{12}$ cfu	%	
Jan	1,544	57.9	644	24.1	201	7.5	201	7.6	31	1.2	31	1.2	7	0	2	0.1	3	0.1	4	0.1	2,668
Feb	1,445	57.9	603	24.2	188	7.5	189	7.6	29	1.2	29	1.2	7	0	2	0.1	2	0.1	3	0.1	2,496
Mar	824	30.9	1,084	40.6	339	12.7	339	12.7	31	1.2	31	1.2	7	0	4	0.2	2	0.1	6	0.2	2,668
Apr	786	30.4	1,055	40.8	330	12.8	330	12.8	30	1.2	30	1.2	7	0	5	0.2	2	0.1	8	0.3	2,582
May	812	30.4	1,087	40.8	340	12.7	340	12.8	31	1.2	31	1.2	7	0	5	0.2	2	0.1	12	0.4	2,668
Jun	786	30.4	1,044	40.4	326	12.6	327	12.7	30	1.2	30	1.2	7	0	5	0.2	1	0.0	26	1.0	2,581
Jul	812	30.4	1,078	40.4	337	12.6	338	12.7	31	1.2	31	1.2	7	0	5	0.2	1	0.0	27	1.0	2,667
Aug	812	30.4	1,078	40.4	337	12.6	338	12.7	31	1.2	31	1.2	7	0	5	0.2	1	0.0	27	1.0	2,667
Sep	786	30.4	1,052	40.8	329	12.7	329	12.8	30	1.2	30	1.2	7	0	5	0.2	2	0.1	12	0.5	2,582
Oct	812	30.4	1,090	40.8	341	12.8	341	12.8	31	1.2	31	1.2	7	0	5	0.2	2	0.1	8	0.3	2,668
Nov	797	30.8	1,050	40.6	328	12.7	328	12.7	30	1.2	30	1.2	7	0	4	0.2	3	0.1	7	0.3	2,584
Dec	1,544	57.8	646	24.2	201	7.5	202	7.5	31	1.2	31	1.2	7	0	2	0.1	3	0.1	4	0.1	2,670
<b>Total<sup>e</sup></b>	<b>11,758</b>	<b>37.3</b>	<b>11,511</b>	<b>36.5</b>	<b>3,596</b>	<b>11.4</b>	<b>3,602</b>	<b>11.4</b>	<b>368</b>	<b>1.2</b>	<b>368</b>	<b>1.2</b>	<b>82</b>	<b>0.3</b>	<b>51</b>	<b>0.2</b>	<b>23</b>	<b>0.1</b>	<b>143</b>	<b>0.5</b>	<b>31,500</b>

<sup>a</sup> Contribution from pastured cattle and wildlife

<sup>b</sup> Contribution from failing septic systems and pets in unsewered households

<sup>c</sup> Assumed equal to rural residential

<sup>d</sup> Contribution from cattle and wildlife depositing in streams and milking parlor wash-off

<sup>e</sup> Fecal coliform production or percentage from different locations may not sum to total values due to rounding error

## **5. MODELING PROCESS FOR TMDL DEVELOPMENT**

A key component in developing a TMDL is establishing the relationship between pollutant loadings (both point and nonpoint) and in-stream water quality conditions. Once this relationship is developed, management options for reducing pollutant loadings to streams can be assessed. In developing a TMDL, it is critical to understand the processes that affect the fate and transport of the pollutants and cause the impairment of the waterbody of concern. Pollutant transport to water bodies is evaluated using a variety of tools, including monitoring, geographic information systems (GIS), and computer simulation models. In this chapter, model description, input data requirements, model calibration procedure and results, and model validation results are discussed.

### **5.1. Model Description**

Development of a TMDL requires the use of a watershed-based model that integrates both point and nonpoint sources and simulates in-stream water quality processes. The Hydrologic Simulation Program – FORTRAN (HSPF) (Bicknell et al., 1993) was used to model fecal coliform transport and fate in the Mill Creek watershed. The BASINS interface (Better Assessment Science Integrating Point and Nonpoint Sources System) Version 2.0 (Lahlou et al., 1998) was used to facilitate use of HSPF. Specifically, the NPSM interface within BASINS provides pre- and post-processing support for HSPF. The ArcView 3.0a or 3.1 GIS provides the integrating framework for BASINS and allows the display and analysis of landscape information.

The HSPF model simulates nonpoint source runoff and pollutant loadings, performs flow routing through streams, and simulates in-stream water quality processes (Donigian et al., 1995). The model HSPF estimates runoff from both pervious and impervious parts of the watershed and stream flow in the channel network. The sub-module PWATER within the module PERLND simulates runoff, and hence, estimates the water budget on pervious areas (e.g., agricultural land). Runoff from largely impervious areas is modeled using the IWATER sub-module within the IMPLND module. Simulation of flow through the stream network is performed using the sub-modules HYDR and ADCALC within the module RCHRES. While HYDR routes the water through the stream network, ADCALC

calculates variables used for simulating convective transport of the pollutant in the stream. Fate of fecal coliform on pervious and impervious land segments is simulated using the PQUAL (PERLND module) and IQUAL (IMPLND module) sub-modules, respectively. Fate of fecal coliform in stream water is simulated using the GQUAL sub-module within the RCHRES module. Fecal coliform bacteria are simulated as a dissolved pollutant using the general constituent pollutant model in HSPF.

## **5.2. Selection of Subwatersheds**

Mill Creek is a small watershed (9,633 ac) and the model framework selected is suitable for this size. To account for the spatial variation of fecal coliform sources, the watershed was divided into six subwatersheds. The stream network was delineated based on the blue line streams on the USGS topographic maps with each subwatershed having at least one stream segment. Since loadings of fecal coliform are believed to be associated with land-use activities and the degree of development in the watershed, the six subwatersheds were chosen based on uniformity of land-use.

## **5.3. Input Data Requirements**

The HSPF model requires a wide variety of input data to describe hydrology, water quality, and land-use characteristics of the watershed. The different types and sources of input data used to develop the TMDL for Mill Creek watershed are discussed below.

### **5.3.1. Climatological Data**

Required weather data were obtained from the weather station closest to the watershed. Hourly precipitation data were obtained from the National Climatic Data Center's (NCDC) cooperative weather station at Dale Enterprise, located 17 miles from the watershed outlet. The entire Mill Creek watershed lies within a 17-mile radius of Dale Enterprise. Since hourly data for other required meteorological parameters, including solar radiation and temperature were not available at Dale Enterprise, daily measured or simulated data from Monterey (Virginia), Lynchburg Airport (Virginia), and Elkins Airport (West Virginia) were used to complete the meteorological data set required for running HSPF. Missing hourly precipitation data were filled in by disaggregating daily precipitation data from Dale Enterprise using hourly precipitation data from Staunton

Sewage Plant as the template data set. Daily precipitation data from Timberville were used to verify daily precipitation data from Dale Enterprise. Detailed descriptions of the weather data and the procedure for converting the raw data into the required data set are included in Appendix B.

### 5.3.2. Hydrology Model Parameters

The hydrology parameters required for simulating runoff by the PWATER and IWATER modules were defined for every land-use category for each subwatershed. For each reach, a function table (FTABLE) is required to describe the relationship between water depth, surface area, volume, and discharge (Donigian et al., 1995). These parameters were estimated by surveying representative channel cross-sections in each subwatershed. Information on stream geometry in each subwatershed is presented in Table 5.1. Hydrology parameters required for the PWATER, IWATER, HYDR, and ADCALC sub-modules are listed in Appendix B.1 of BASINS ver. 2.0 User's Manual (Lahlou et al., 1998). Parameters required as inputs for PQUAL, IQUAL, and GQUAL are given Appendix B.1 of BASINS ver. 2.0 User's Manual (Lahlou et al., 1998). Runoff estimated by the model is also an input to the water quality components. Values for the parameters were estimated based on local conditions when possible, otherwise the default parameters provided within HSPF were used.

**Table 5.1. Stream characteristics of Mill Creek watershed**

Subwatershed	Stream length (mile)	Average width (ft)	Average channel depth (ft)	Slope (ft/ft)
MLC-A	0.95	9.84	0.57	0.0020
MLC-B <sup>a</sup>	2.19	3.28 (9.84)	0.28 (0.57)	0.0004 (0.0005)
MLC-C	3.02	1.64	0.22	0.0006
MLC-D	3.18	1.64	0.08	0.0006
MLC-E	2.76	3.28	0.28	0.0151
MLC-F	0.49	21.32	0.16	0.0618

<sup>a</sup> The stream in this subwatershed is characterized as two stream reaches with the width, depth, and slope of the shorter stream reach (0.39 miles) given in parentheses

### 5.3.3. Land-use

Virginia DCR identified 31 land-use types in the watershed. As described in Chapter 3, the 31 land-use types were consolidated into nine categories based on hydrologic and waste application/production characteristics (Table 3.1). The land-use categories were assigned pervious/impervious percentages which allowed a land-use with both pervious

and impervious fractions to be modeled using both the PERLND and IMPLND modules. Land-use data were used to select several hydrology and water quality parameters for the simulations.

## **5.4. Accounting for Pollutant Sources**

### **5.4.1. Overview**

There are no VADEQ permitted point source discharges in the Mill Creek watershed. However, fecal coliform loads that are directly deposited by cattle and wildlife in streams were treated as direct nonpoint sources in the model. Fecal coliform that is land-applied or deposited on land was treated as nonpoint source loading; all or part of that load may get transported to the stream as a result of surface runoff during rainfall events.

Direct nonpoint source loading was applied to the stream reach in each subwatershed as appropriate. The nonpoint source loading was applied as fecal coliform counts to each land-use category in a subwatershed on a monthly basis. Fecal coliform was considered to die-off in land-applied sources, stored manure, and in the stream. Both direct nonpoint and nonpoint source loadings were varied by month to account for seasonal differences.

### **5.4.2. Modeling fecal coliform die-off**

Fecal coliform die-off was modeled using a first order die-off equation of the form:

$$C_t = C_0 10^{-Kt} \quad [5-1]$$

where:  $C_t$  = concentration or load at time  $t$ ,  $C_0$  = starting concentration or load,  $K$  = decay rate ( $\text{day}^{-1}$ ), and  $t$  = time (days). A review of literature provided estimates of decay rates that could be applied to waste storage and handling in the Mill Creek watershed (Table 5.2).



**Table 5.2. First order decay rates for different animal waste storage as affected by storage/application conditions and their sources**

Waste type	Storage/application	Decay rate, day <sup>-1</sup>	Reference
Dairy manure	Pile (not covered)	0.066	Jones (1971) <sup>a</sup>
	Pile (covered)	0.028	
Beef manure	Anaerobic lagoon	0.375	Coles (1973) <sup>a</sup>
Poultry litter	Soil surface	0.035	Giddens et al. (1973)
		0.342	Crane et al. (1980)

<sup>a</sup> Cited in Crane and Moore (1986)

Based on the values cited in the literature, the following decay rates were used in simulating fecal coliform die-off in stored waste.

- Liquid dairy manure: Since the decay rate for liquid dairy manure storage could not be found in the literature, the decay rate for beef manure in anaerobic lagoons (0.375 day<sup>-1</sup>) was used assuming that the storage creates anaerobic conditions.
- Solid cattle manure: Based on the range of decay rates (0.028-0.066 day<sup>-1</sup>) reported for solid dairy manure, a decay rate of 0.05 day<sup>-1</sup> was used assuming that a majority of manure piles are not covered.
- Poultry waste in pile/house: Since no decay rates were found for poultry waste in storage, a decay rate of 0.035 day<sup>-1</sup> was used based on the lower decay rate reported for poultry litter applied to the soil surface. The lower value was used instead of the higher value of 0.342 day<sup>-1</sup> (Table 5.2.) since fecal coliform die-off in storage was assumed to be lower, given the absence of UV radiation and lack of predation by soil microbes.

The procedure for calculating fecal coliform counts in waste at the time of land application is included in Appendix C. The method used to calculate the fraction of fecal coliform surviving in the manure at the end of storage considered the duration of storage, type of storage, type of manure, and die-off factor. When calculating survival fraction at the end of the storage period, the daily addition of manure and coliform die-off of each fresh manure addition is considered to arrive at an effective survival fraction over the entire storage period. The amount of fecal coliform available for application to land per year is estimated by multiplying the survival fraction with total fecal coliform produced per year (in as-excreted manure). Monthly fecal coliform application to land was estimated by multiplying the amount of fecal coliform available for application to land per year by the fraction of manure applied to land during that month. A decay rate

of  $0.045 \text{ day}^{-1}$  was assumed for fecal coliform on the land surface. The decay rate of  $0.045 \text{ day}^{-1}$  is represented in HSPF by specifying a maximum surface buildup of nine times the daily loading rate. An in-stream decay rate of  $1.15 \text{ day}^{-1}$  (USEPA, 1985) was used.

#### **5.4.3. Modeling Nonpoint Sources**

For modeling purposes, nonpoint fecal coliform loads were those that were deposited or applied to land and, hence, required runoff events to transport to streams. Fecal coliform loading (cfu/month) by land-use for all sources in the watershed is presented in Table 5.3. Total manure production was calculated using animal population and waste produced per day per animal. Animal numbers for the watershed were supplied by VADCR. These numbers were further refined by consulting with producers and Virginia Cooperative Extension faculty located in that county. The refined animal numbers were also checked against pasture acreage (for beef) and housing capacity (for poultry) to ensure that the estimates were reasonable. For dairy cattle population, the number of dairies in each subwatershed and the number of dairy cattle in each dairy farm were estimated in consultation with producers. The numbers on daily waste production from different animal species were obtained from published sources such as the ASAE Standards or Virginia Nutrient Management Standards Criteria. Estimation of manure produced in different locations (e.g., confinement, pastures) were based on guidelines provided by VADCR which were confirmed or modified through discussion with producers and extension personnel. Fecal coliform loadings to the individual subwatersheds are presented in Appendix D.

Of all the fecal coliform excreted in the watershed (excluding fecal coliform deposited in the stream) (Table 4.13), 35% of the coliform die-off in storage prior to land application and the remaining 65 % is applied to the land as a NPS load (Table 5.3). The sources of fecal coliform to different land-use categories and how they were handled by the model are briefly discussed below.

1. Cropland: Liquid dairy manure, solid manure, and poultry litter is applied to cropland as described in Chapter 4. Fecal coliform loadings to cropland were adjusted to account for die-off during storage and partial incorporation during land-application (Sections 4.2.5, 4.2.6, and 4.3). For modeling, monthly fecal coliform loading

assigned to cropland was distributed over the entire cropland acreage within a subwatershed. Thus, loading rate varied by month and subwatershed.

**Table 5.3. Monthly nonpoint fecal coliform loadings to the different land-use categories in Mill Creek watershed**

Month	Fecal coliform loadings ( $\times 10^{12}$ cfu/month)									Total by month ( $\times 10^{12}$ cfu)
	Crop-land	Past. 1	Past. 2	Past. 3	Rural Resid-entia	Farm-stead	Urban Resid-entia	Loafing lot	Forest	
Jan.	0	681	193	172	30	30	7	1	5	1,120
Feb.	39	638	181	161	28	28	7	1	3	1,086
Mar.	194	1,147	325	291	30	30	7	4	3	2,031
Apr.	155	1,116	315	284	29	29	7	4	3	1,943
May	39	1,151	325	292	30	30	7	4	3	1,882
Jun.	0	1,155	312	279	29	29	7	4	3	1,818
Jul.	0	1,190	322	288	30	30	7	4	3	1,875
Aug.	0	1,191	322	288	30	30	7	4	3	1,876
Sep.	0	1,211	315	283	29	29	7	4	3	1,881
Oct.	58	1,153	326	293	30	30	7	4	3	1,905
Nov.	59	1,111	314	282	29	29	7	3	5	1,840
Dec.	0	683	193	173	30	30	7	1	5	1,123
<b>Total</b>	544	12,427	3,443	3,088	358	358	82	40	39	20,381

- Pasture 1: In addition to direct deposition from cattle and wildlife, pasture 1 receives applications of liquid dairy manure, solid manure, and poultry litter as described in Chapter 4. Applied fecal coliform loading to pasture 1 was reduced to account for die-off during storage. For modeling, monthly fecal coliform loading assigned to Pasture 1 was distributed over the entire pasture 1 acreage within a subwatershed.
- Pasture 2 and pasture 3: Fecal coliform loadings resulting from direct waste deposition by cattle and wildlife were spread over pasture 2 and pasture 3 acreages in each subwatershed.
- Rural Residential: Fecal coliform loading on rural residential land-use came from failing septic systems and waste from pets. In the model simulations, fecal coliform loads produced by failing septic systems and pets in a subwatershed (Table 4.1) were combined and assumed to be uniformly applied to the rural residential land-use areas.
- Farmstead: The total fecal coliform load to farmstead land-use was assumed to be the same as loads for the rural residential land-use.

6. Urban Residential: Fecal coliform loading from waste produced by pets living in sewerred households was applied uniformly over the entire urban residential acreage. For subwatersheds with urban residential acreage but no sewerred households, no load was applied to the urban residential land-use (Appendix D) since this land-use also includes other categories, such as, transitional and disturbed areas (Table 3.1).
7. Loafing Lot: Fecal coliform loads resulting from direct waste deposition by milk cows was spread uniformly over the entire loafing lot acreage in each subwatershed.
8. Forest: Wildlife not defecating in streams and pastures provided fecal coliform loading to the forest land-use. Fecal coliform, except for the percentage considered as direct load to the stream, was applied uniformly over the forest areas.

#### 5.4.4. Modeling Direct Nonpoint Sources

Fecal coliform loads from direct nonpoint sources were cattle and wildlife in streams (Table 5.4). There are no straight pipes from residences or milking parlors discharging directly to streams in this watershed. A comparison of Tables 5.3 and 5.4 shows that the annual direct nonpoint source loading to the stream is 0.7% of the annual nonpoint source loading to the land.

**Table 5.4. Monthly direct nonpoint source loads to the stream for each subwatershed**

Month	Monthly fecal coliform loads by subwatershed ( ´ 10 <sup>9</sup> cfu/month) <sup>a</sup>												Monthly loading ( ´ 10 <sup>9</sup> cfu)
	MLC-A		MLC-B		MLC-C		MLC-D		MLC-E		MLC-F		
	Cattle	Wild life	Cattle	Wild life	Cattle	Wild life	Cattle	Wild life	Cattle	Wild life	Cattle	Wild life	
Jan.	136	20	342	61	263	47	766	123	714	18	0	1,036	3,526
Feb.	127	19	320	57	246	44	716	115	668	17	0	534	2,863
Mar.	339	20	883	61	656	47	1,933	104	1,821	18	0	553	6,435
Apr.	437	19	1,159	59	847	46	2,507	100	2,374	17	0	535	8,100
May	678	20	1,797	61	1,313	47	3,886	104	3,680	18	0	553	12,157
Jun.	1,531	19	4,057	59	2,964	46	8,775	64	8,309	17	0	498	26,339
Jul.	1,582	20	4,192	61	3,063	47	9,068	66	8,586	18	0	515	27,218
Aug.	1,582	20	4,192	61	3,063	47	9,068	66	8,586	18	0	515	27,218
Sep.	656	19	1,739	59	1,270	46	3,761	119	3,561	17	0	553	11,800
Oct.	452	20	1,198	61	875	47	2,591	123	2,453	18	0	571	8,409
Nov.	328	19	854	59	635	46	1,870	119	1,762	17	0	1,002	6,711
Dec.	136	20	342	61	263	47	766	123	714	18	0	1,036	3,526
Total	7,983	236	21,074	715	15,455	555	45,706	1,224	43,231	211	0	7,900	144,290

<sup>a</sup> Fecal coliform loads applied by cattle and wildlife directly to streams

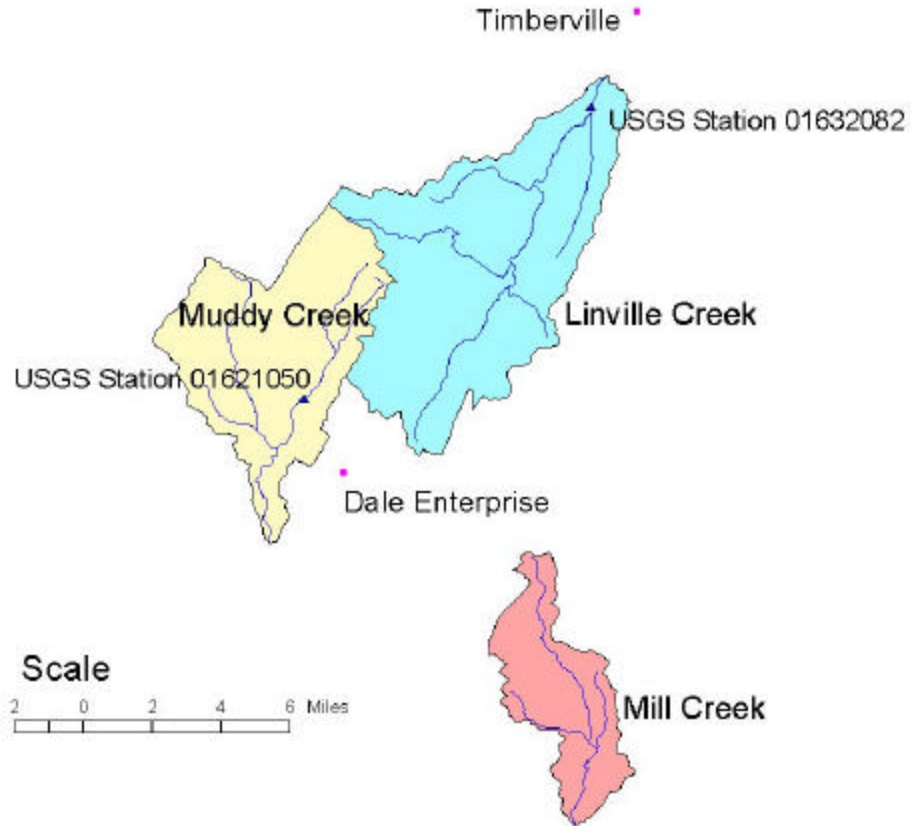
## **5.5. Model Calibration and Validation**

Model calibration is the process of selecting model parameters that provide an accurate representation of the watershed. Validation ensures that the calibrated parameters are appropriate for time periods other than the calibration period. In this section, the procedures followed for calibrating the hydrology and water quality components of the HSPF model are discussed. The calibration and validation results of the hydrology component, and the calibration results of the water quality component are presented.

### **5.5.1. Hydrology Procedure**

For the hydrologic component of the HSPF calibration, observed values for daily stream flow are required. Although monthly observations of stream flow are available for Mill Creek for a 37-month period, daily discharge records are not available. Daily discharge observations are available from two USGS flow monitoring stations located in watersheds near Mill Creek. The USGS station at Mount Clinton, Virginia (Station Number 01621050) has daily discharge observations for a portion of the Muddy Creek watershed. The drainage area monitored at the station is 14.2 square miles (9,088 acres) and the available period of record is April 1993 through September 1998 (approximately 5 years). The other USGS station is located near Broadway, Virginia (Station Number 01632982), and has daily discharge observations for the Linville Creek watershed. The drainage area monitored at the station is 45.5 square miles (29,120 acres) and the available period of record is August 1985 through September 1998 (approximately 13 years).

The locations of the Linville Creek and Muddy Creek watersheds relative to Mill Creek are shown in Figure 5.1. The hourly precipitation gage at Dale Enterprise (Figure 5.1) was the main gage used for model calibration and the National Climatic Data Center's daily precipitation data at Timberville were used to verify and supplement the Dale Enterprise data.



**Figure 5.1. Location of calibration and validation watersheds relative to the Mill Creek watershed.**

The hydrology calibration was performed using the Linville Creek data because the period of record was longer than that available for the Muddy Creek watershed. This longer period of record ensured that a representative time period that included both wet and dry periods was included in the calibration period. Also, the longer period of record from Linville Creek provided enough data to conduct validation runs of the same length as the calibration runs. Furthermore, similarity in land-use characteristics between the Mill Creek and Linville Creek watersheds (Table 5.5) indicated the appropriateness of using the Linville Creek watershed for calibrating the HSPF model.

**Table 5.5. Comparison of land-use distribution between Mill Creek and Linville Creek watersheds**

Land-use	Mill Creek	Linville Creek
Cropland	22.6%	21.4%
Pasture	44.6%	49.4%
Forest	11.3%	15.7%
Rural residential	6.9%	8.3%

The calibration period selected for the Linville Creek data was September 1, 1991 to March 1, 1996, and the validation period was September 1, 1986 to August 31, 1991. The Muddy Creek daily discharge observations were also used as an independent evaluation of the calibrated input data set. The period of record used from Muddy Creek was April 13, 1993 to July 31, 1996. The additional validation runs using the Muddy Creek data provided a measure of the transferability of the calibrated data set from Linville Creek to other nearby watersheds.

The HSPEXP decision support software (Lumb et al., 1994) was used to develop a calibrated HSPF data set for the Linville Creek calibrations. The HSPEXP system provides guidance on parameter adjustment during the calibration process. This guidance is provided through a decision support system that is based on the experience of expert modelers in applying HSPF to various types of watersheds (Lumb et al., 1994). Accuracy of HSPF simulation results is measured in HSPEXP by comparing simulated and observed daily discharge values. Comparison of simulated and observed data is conducted for several parameters including annual water balances, seasonal variability of baseflow, and storm events, and for the overall time series. HSPEXP requires the user to identify a set of storms to investigate the accuracy of the simulated storm response during each season. Guidance for storm selection is given in the HSPEXP user manual (Lumb et al., 1994). For the calibration period, 29 storm events were selected from the Linville Creek watershed. For the validation period, 24 storm events were selected from Linville Creek and seven from Muddy Creek. A smaller number of storms was used for Muddy Creek because of the shorter period of record available for this watershed. Values for parameters that represent the different levels of accuracy are calculated for both the simulated and observed data and compared as a percent error in HSPEXP. The guidance provided by HSPEXP is based on the percent error between the various observed and simulated values for each parameter (Lumb et al., 1994). The default criteria recommended in HSPEXP were used in the Linville Creek calibration and are listed in Table 5.6. These same criteria were used in the validation of the model.

**Table 5.6. Calibration Criteria Used in HSPEXP for Hydrologic Calibration.**

Variable	Percent Error Criteria
Total Volume	±10%
Low Flow Recession	±0.010%
50% Lowest Flows	±10%
10 % Highest Flows	±15%
Storm Peaks	±15%
Seasonal Volume Error	±10%
Summer Storm Volume Error	±15%

### **Results**

The calibration of the HSPF hydrology parameters resulted in simulated flows that accurately matched the observed data for Linville Creek. A comparison of the simulated and observed stream flow data is given in Table 5.7 for the calibration period of September 1, 1991 to March 1, 1996 for Linville Creek. There was very good agreement between the observed and simulated stream flow indicating that the model represented the hydrologic characteristics of the watershed very well. Percent error for each variable is within the criteria specified by HSPEXP. In Figure 5.2, the simulated and observed stream flow for a smaller period within the calibration period is shown. The simulated data follow the pattern of the observed data very well. The model closely simulates both low flows and storm peaks.

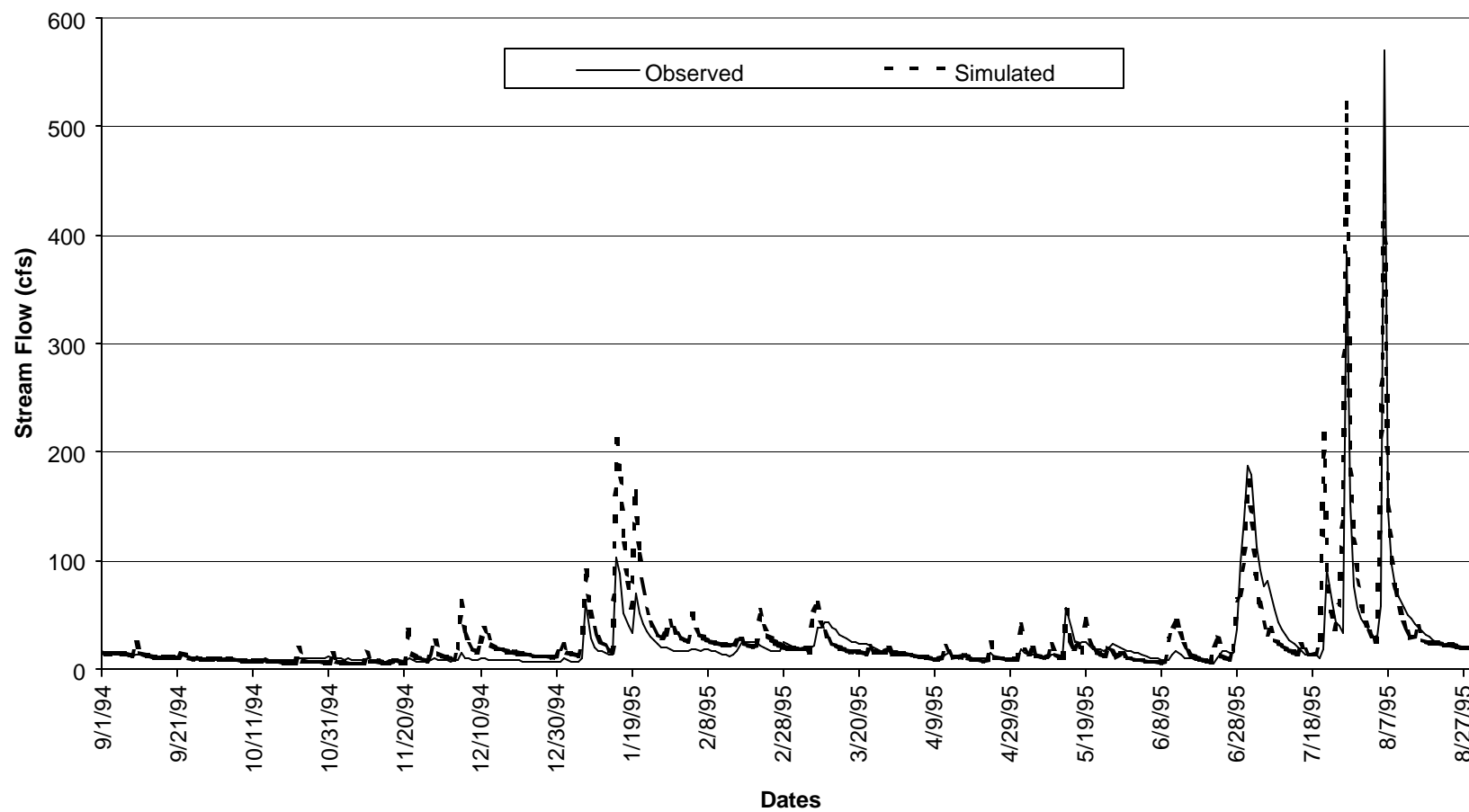
**Table 5.7. Linville Creek calibration simulation results (September 1, 1991 to March 1, 1996).**

Parameter	Simulated (inches)	Observed (inches)	% Percent Error
Total stream flow	54.9	55.2	-0.5%
Summer <sup>a</sup> stream flow	7.6	7.5	0.01%
Winter <sup>b</sup> stream flow	20.2	21.5	-6.0%

<sup>a</sup> June – August

<sup>b</sup> December – February





**Figure 5.2. Simulated and observed stream flow for Linville Creek for a portion of the calibration period (Sept. 1, 1994 to August 31, 1995).**

The calibrated data set was then used in the model to predict runoff for a different time period for Linville Creek to provide a basis for evaluating the appropriateness of the calibrated parameters. A comparison of the simulated and observed stream flow data is given in Table 5.8 for the validation period of September 1, 1986 to August 31, 1991 for Linville Creek.

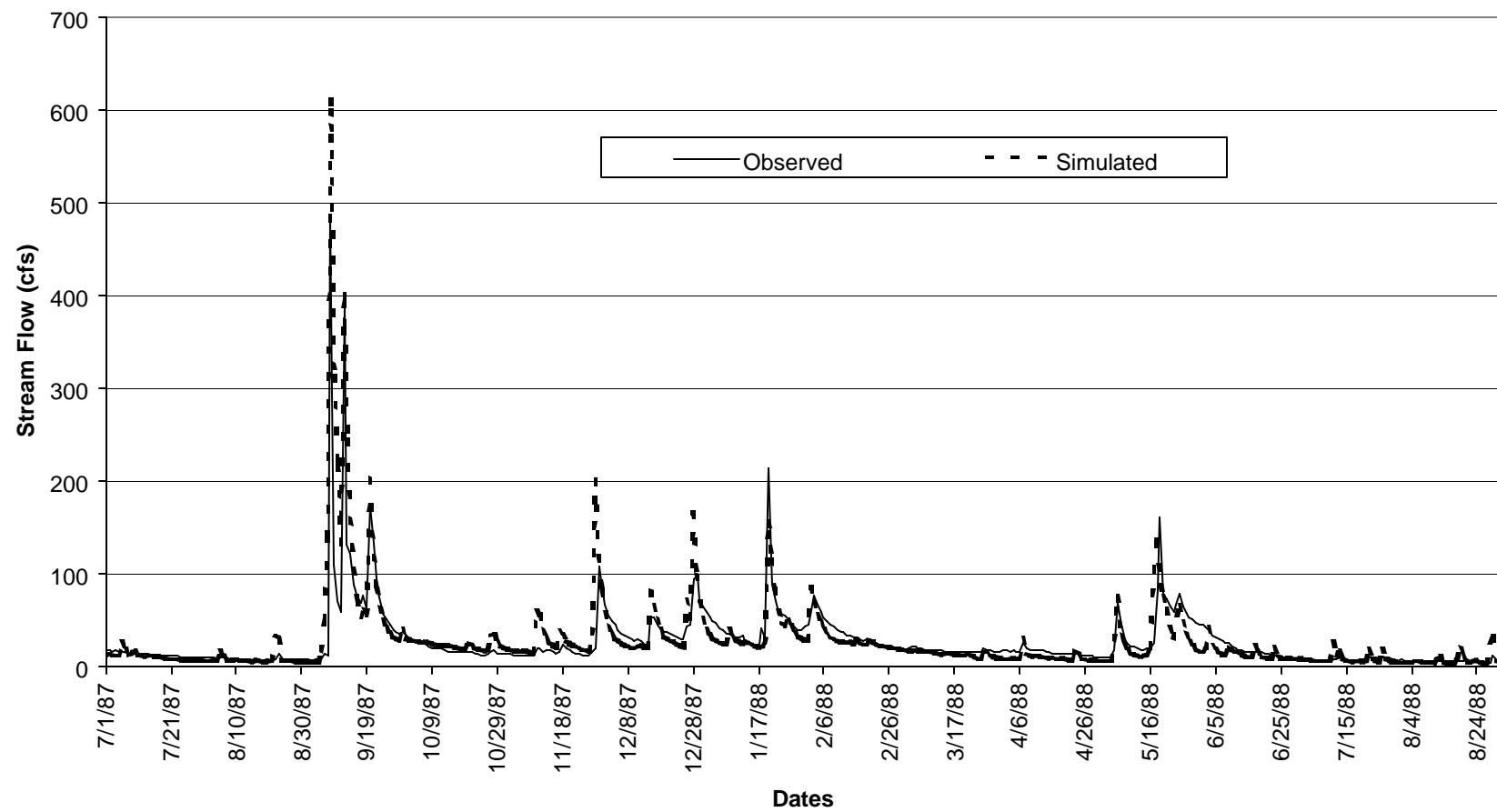
**Table 5.8. Linville Creek validation simulation results (September 1, 1986 to August 31, 1991).**

<b>Parameter</b>	<b>Simulated (inches)</b>	<b>Observed (inches)</b>	<b>% Percent Error</b>
Total stream flow	51.4	48.0	7.1%
Summer <sup>a</sup> stream flow	7.5	6.5	15.4%
Winter <sup>b</sup> stream flow	15.6	14.4	8.3%

<sup>a</sup> June – August

<sup>b</sup> December - February

There was very good agreement between the observed and simulated stream flow, indicating that the calibrated parameters represent the characteristics of the watershed reasonably well for time periods in addition to the calibration period. The simulated and observed stream flow for a smaller period within the validation period is shown (Figure 5.3). The simulated data follow the pattern of the observed data well.



**Figure 5.3. Simulated and observed stream flow for Linville Creek during the period of July 1, 1987 to July 31, 1998.**

To test if the calibrated input data set for Linville Creek represents the hydrologic processes of other watersheds in the region, an additional validation run was conducted for the Muddy Creek watershed for the period of April 13, 1993 to June 30, 1995. As with Linville Creek, there was good agreement between the simulated and observed stream flow (Table 5.9). For the Muddy Creek validation, the total and summer (June – August) stream flows were excellent, but the winter (December – February) stream flow error exceeded the desired criterion of 10% error. In spite of the high winter stream flow error, the hydrology portion of the model was judged to be successfully validated because of the success of the calibrated data set with the longer Linville Creek validation period. In addition, the calibrated data set did a good job of representing summer stream flow conditions when the highest fecal coliform concentrations occur. The significance of the Muddy Creek winter storm flow error was also considered less significant because the climatic data during the two winter periods simulated was considerably higher than average and not representative of long-term climatic patterns. The high percent error for the winter stream flow was also possibly due to errors in the precipitation data, which would be magnified because of the short duration of the validation period.

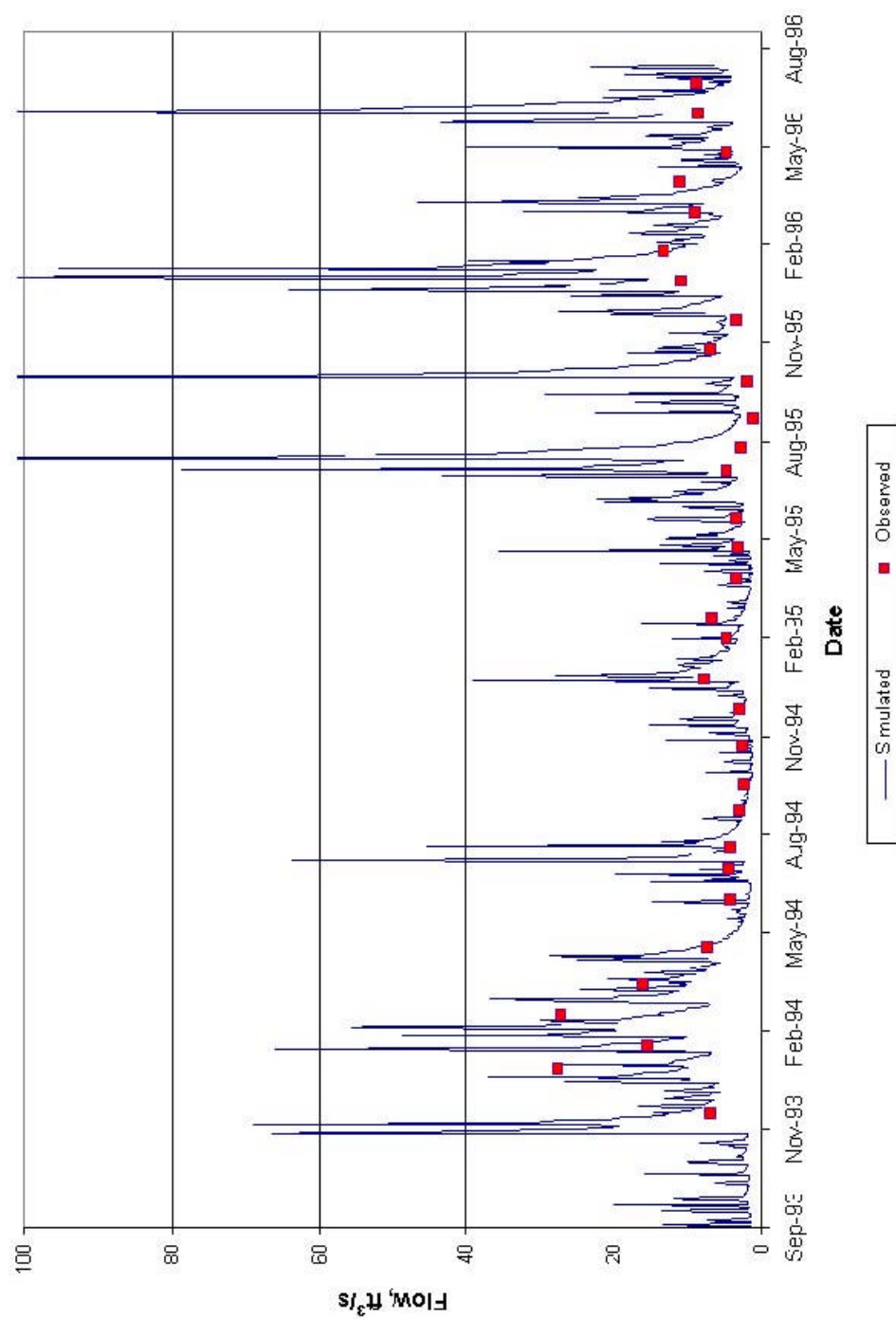
**Table 5.9. Summary Values for Muddy Creek Validation Simulation.**

<b>Parameter</b>	<b>Simulated (in.)</b>	<b>Observed (in.)</b>	<b>Percent Error</b>
Total stream flow	21.5	19.5	10.3%
Summer <sup>a</sup> stream flow	3.0	3.2	-6.3%

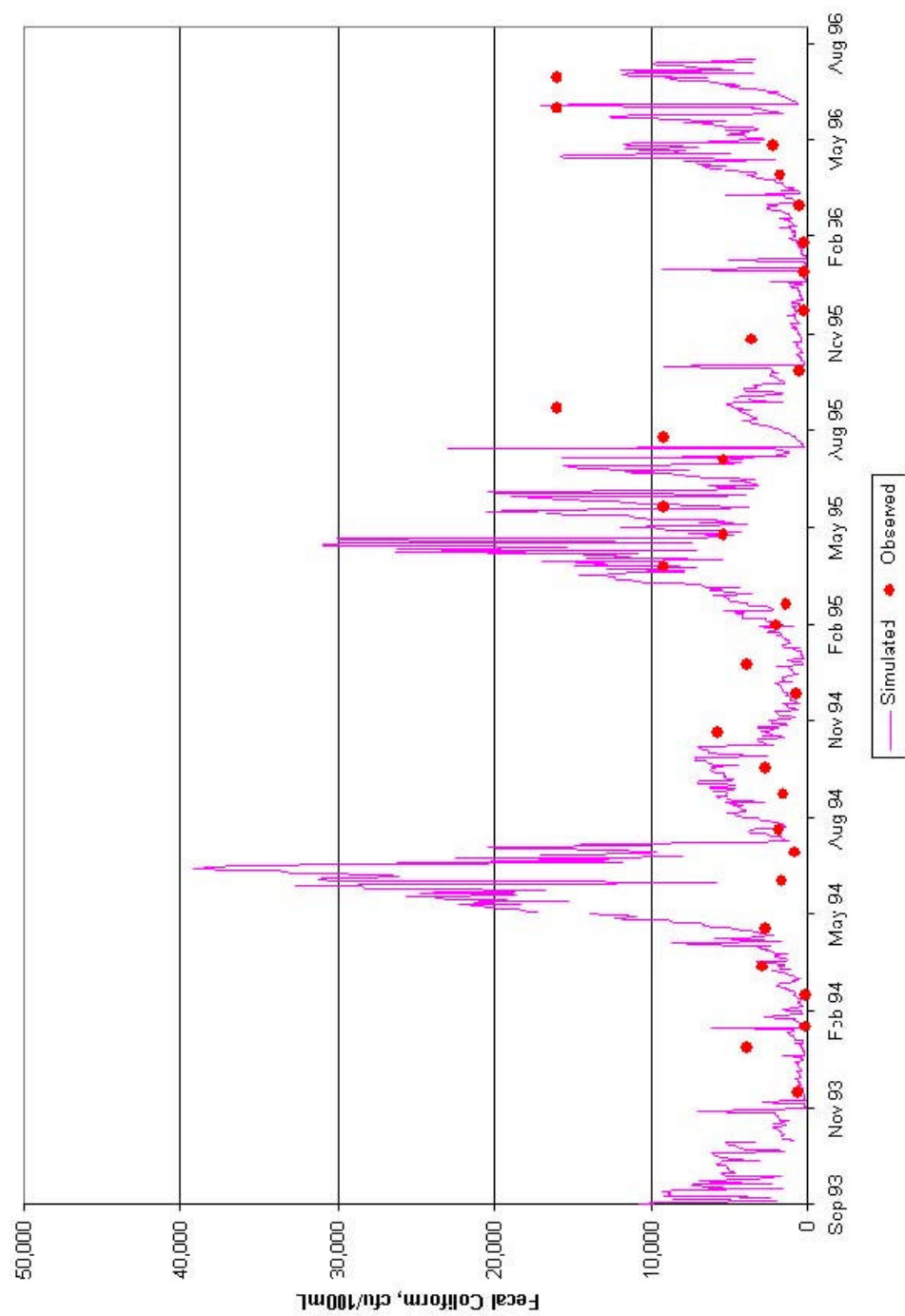
<sup>a</sup> June – August

In general, the validation results from both Linville and Muddy Creeks indicate that the calibrated model characterizes the hydrologic processes of the region well. Therefore, the calibrated parameters were assumed to provide a good first estimate of parameters required to simulate the hydrology of Mill Creek watershed for TMDL development purposes. Due to lack of sufficient stream flow data from Mill Creek, a detailed analysis of the model's performance for this watershed was not possible. As a qualitative comparison, the simulated daily stream flow and the monthly flow measurements are shown in Figure 5.4. Several hydrology parameters were changed to provide a better fit of the observed and simulated Mill Creek flow rates. Some of these parameters lowered base flow predictions, which the model had slightly over-predicted. The parameter DEEPFR (fraction of groundwater inflow entering deep groundwater and be lost) was

increased from 0.19 to 0.25. Similarly, the interflow recession parameter, IRC was increased from 0.60 to 0.75. The final values for infiltration index parameter (INFILT) and interflow inflow (INTFLW) were 0.15, and 1.8, respectively. After these adjustments, there is now good agreement between the simulated stream flow and monthly observations. Partitioning of the total flow indicated that surface flow (SURO), interflow (IFWO), and active groundwater (AGWO) accounted for 15.08%, 37.48%, and 47.44% of the flow, respectively. Based on the results for all three watersheds, it can be concluded that the HSPF model adequately represents the hydrology of Mill Creek.



**Figure 5.4. Simulated average daily stream flow and monthly stream flow measurements for Mill Creek.**



**Figure 5.5. Mill Creek fecal coliform calibration for existing conditions**

### 5.5.2. Fecal coliform calibration

#### Procedure

After the hydrologic calibration and validation were completed, the water quality component of HSPF was calibrated. Sixty-four fecal coliform samples for the Mill Creek watershed were collected by VADEQ from September 1993 to December 1998. Since the complete meteorological data set only extended until July 1996, 35 samples (September 1993 – July 1996) were used for calibration. The accuracy of the simulations was assessed visually using graphs of simulated and observed values. Further assessment of simulation accuracy beyond July 1996 was not feasible due to the lack of weather data.

#### Results

The primary water quality parameter adjusted during calibration was the daily fecal coliform production value for beef and dairy cattle. This parameter was adjusted until there was good agreement between simulated and observed concentrations. Values of daily fecal coliform production for cattle published in the literature range from 5.4 to 132 billion cfu/animal-day. The calibrated values were 20.0 and 25.8 billion cfu/animal – day, for dairy and beef, respectively. The calibrated values are within the reported range. Other HSPF fecal coliform parameters used in model calibration are presented in Table 5.10.

**Table 5.10. Fecal coliform parameters<sup>a</sup> used in the Mill Creek study**

Module/sub-module	Parameter	Value
PERLND/PQUAL	WSQOP	2.4 in./h
	IOQC	1461 cfu/ft <sup>3</sup>
	AOQC	1461 cfu/ft <sup>3</sup>
	SQO	10 <sup>9</sup> – 10 <sup>11</sup> cfu/acre <sup>b</sup>
	POTFW	0 cfu/ton
	POTFS	0 cfu/ton
IMPLND/IQUAL	SQO	10 <sup>7</sup> cfu/acre
	POTFW	0 cfu/ton
	WSQOP	2.4 in./h
RCHRES/GQUAL	FSTDEC	1.15 day <sup>-1</sup>
	THFST	1.05

<sup>a</sup> See Lahlou et al. (1998) for description

<sup>b</sup> Function of land-use type



## 6. LOAD ALLOCATIONS

### 6.1. Background

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1991). The objective of the TMDL plan for Mill Creek was to determine what reductions in fecal coliform loadings from point and nonpoint sources are required to meet state water quality standards. The state water quality standard for fecal coliform used in the development of the TMDL was 200 cfu/100mL (30-day geometric mean). The TMDL considers all sources contributing fecal coliform to Mill Creek. The sources can be separated into nonpoint and point sources. The incorporation of the different sources into the TMDL are defined in the following equation:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS} \quad [6.1]$$

where,

WLA = waste load allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

A margin of safety (MOS) is included to account for any uncertainty in the TMDL development process. There are several different ways that the MOS could be incorporated into the TMDL (EPA, 1991). For the Mill Creek TMDL, a MOS of 5% was incorporated explicitly in the TMDL equation, in effect reducing the target fecal coliform concentration (30-day geometric mean) to 190 cfu/100mL from 200 cfu/100mL.

The time period selected for the load allocation study was from September 20, 1993 to July 16, 1996, the same period for which observed data were available. This period was selected because it covers the period in which water quality violations were observed and it incorporates a wide range of hydrologic events including both low and high flow conditions.

## 6.2. Existing Conditions

Analyses of the simulation results for the existing conditions in the watershed for the period September 20, 1993 to July 16, 1996 (Table 6.1) show that direct deposition of manure by cattle into the stream is the primary source of fecal coliform in the stream. Direct deposition of manure by cattle into Mill Creek is responsible for 92.1 % of the mean daily fecal coliform concentration. In the summer, when cattle on pastures with stream access spend 3.5 hours in the stream, direct deposits are a critical source. Of the 667 cattle on pastures with access to the stream in the summer, an equivalent of 97 cattle spend the entire day in the stream. Since 30% of the cattle in the stream are assumed to defecate in the stream, waste from 29 cattle is directly deposited in the stream. This amounts to 4.4% of the entire manure load produced by all cattle on pastures with stream access. The fraction of manure directly deposited in the stream at other times of the year was lower, but still caused problems during extended low flow periods.

**Table 6.1. Relative contributions of different fecal coliform sources to the overall fecal coliform concentration for the existing conditions in Mill Creek watershed.**

<b>Source</b>	<b>Mean daily fecal coliform concentration attributable to source, cfu/100mL</b>	<b>Relative Contribution by Source, %</b>
All sources	4,977	100.0
Point source direct deposits of dairy and beef cattle manure to the stream	4,604	92.1
Nonpoint source loadings from pervious land segments	219	4.4
Point source loadings to the stream from wildlife	152	3.1
Nonpoint source loadings from impervious land-use	2	0.4

Fecal coliform loadings from direct nonpoint sources, such as from cattle in streams, affect water quality mainly under low-flow conditions, resulting in high concentrations of fecal coliform. As shown in Table 6.1, direct fecal coliform loading by cattle in the stream result in much higher mean daily fecal coliform concentration (4,604 cfu/100 mL) than nonpoint fecal coliform loading from upland areas (219 cfu/100 mL).

### 6.3. Allocation Scenarios

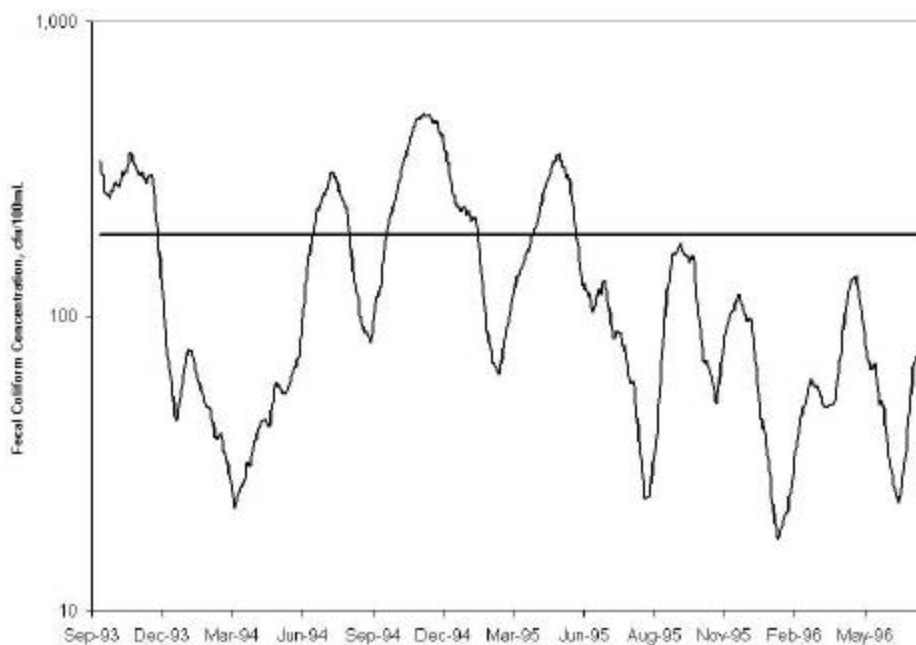
A variety of allocation scenarios were evaluated to meet the TMDL goal of a 30-day geometric mean of 190 cfu/100mL. The TMDL scenarios and results are summarized in Table 6.2. Because direct deposit of fecal coliform by cattle into streams contributes 92% of the mean daily fecal coliform concentration, all allocation scenarios include elimination or drastic reduction of direct deposits by cattle.

**Table 6.2. Allocation scenarios for Mill Creek watershed**

Scenario Number	Percent Reduction in Loading from Existing Condition				
	Direct wildlife deposits	Direct cattle deposits	NPS from pervious land segments	NPS from impervious land segments	Percentage of days with 30-day GM > 190 cfu/100mL
<b>1</b>	0.0	100.0	100.0	100.0	39.9
<b>2</b>	25.0	96.5	0.0	0.0	60.5
<b>3</b>	75.0	99.0	0.0	0.0	16.0
<b>4</b>	<b>70.0</b>	<b>100.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>

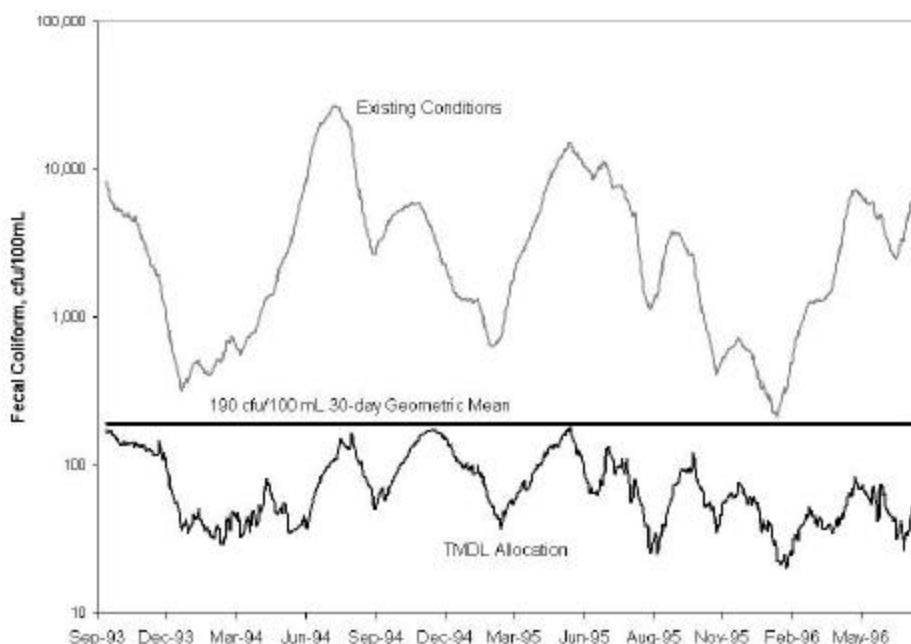
Scenario 1 involved assessing the contribution of wildlife alone to Mill Creek. In this scenario, contributions from all other sources of fecal coliform loadings in the model were turned off, except for fecal coliform deposited directly in the stream by wildlife. As shown in Figure 6.1, the fecal coliform loading due to wildlife causes fecal coliform concentrations in the stream to violate the 30-day geometric mean goal of 190 cfu/100mL. In fact, the 30-day geometric mean goal is exceeded 40% of the time and reaches a peak value of approximately 480 cfu/100mL. This implies that it is not possible to develop a TMDL that meets the current state water quality standards only by reducing sources of fecal coliform caused by human activity.

Compliance with the current water quality standard will require reductions in both human (including livestock) and wildlife sources of fecal coliform. After consulting with VADCR, it was agreed that a TMDL allocation would be developed by reducing both human (including livestock) and natural (wildlife) sources of fecal coliform. Simulations were then conducted to identify the required reduction in wildlife loadings as presented in Scenarios 2, 3, and 4 (Table 6.2).



**Figure 6.1. Thirty-day geometric mean of fecal coliform loading from direct wildlife contribution to stream (Scenario 1) in the Mill Creek watershed.**

Only Scenario 4 (Table 6.2) meets the TMDL allocation requirement of no violation of the 190 cfu/100mL 30-day geometric mean goal. Fecal coliform concentrations resulting from Scenario 4 as well as the existing conditions are presented graphically in Figure 6.2. Scenario 4 requires a 70% reduction in direct fecal coliform loading to the stream from wildlife. With Scenario 4, no reduction in nonpoint sources of fecal coliform is required. Nonpoint source loadings by land-use for existing conditions are presented in Table 6.3. However, Scenario 4 still requires total exclusion of directly deposited cattle manure from streams. Fecal coliform loads from direct nonpoint sources under existing conditions and for the allocation scenario (Scenario 4) are presented in Table 6.4. Comparison of existing and allocation loads from both nonpoint and direct nonpoint sources for each subwatershed is given in Appendix E.



**Figure 6.2. Thirty-day geometric mean of fecal coliform for Mill Creek watershed for the existing conditions and Allocation Scenario 4**

**Table 6.3. Annual nonpoint source loads under existing conditions and corresponding reductions for TMDL allocation scenario 4.**

Land-use Category	Existing conditions		Allocation scenario	
	Existing load ( $\times 10^{12}$ cfu)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load ( $\times 10^{12}$ cfu)	Percent reduction from existing load
Cropland	77.8	4.9	77.8	0.0
Pasture 1	1307.8	82.0	1307.8	0.0
Pasture 2	110.7	6.9	110.7	0.0
Pasture 3	48.0	3.0	48.0	0.0
Farmstead	2.7	0.2	2.7	0.0
Rural Residential	32.2	2.0	32.2	0.0
Urban Residential	10.6	0.7	10.6	0.0
Loafing Lot	0.1	<.01	0.1	
Forest	3.9	0.2	3.9	0.0
<b>Total</b>	<b>1,593.8</b>	<b>100.0</b>	<b>1,593.8</b>	<b>0.0</b>

**Table 6.4. Annual direct nonpoint source load reductions for TMDL allocation scenario 4.**

Source	Existing conditions load ( $\times 10^{12}$ cfu)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load ( $\times 10^{12}$ cfu)	Percent reduction
Cattle in Streams	133.5	92.5	0	100.0
Wildlife in Streams	10.8	7.5	3.2	70.0
<b>Total</b>	<b>144.3</b>	<b>100.0</b>	<b>3.2</b>	<b>97.8</b>

Based on the information provided in Tables 6.3 and 6.4, the total annual fecal coliform load from both nonpoint and direct nonpoint sources is  $1738.1 \times 10^{12}$  cfu. More than 91% of the total annual fecal coliform is from nonpoint sources. The TMDL allocation load for both nonpoint and direct nonpoint sources added up to  $1597 \times 10^{12}$  cfu, a reduction of 8% compared to the existing load.

#### 6.4. Summary of TMDL Allocation Plan

A TMDL for fecal coliform has been developed for Mill Creek. The TMDL addresses the following issues.

1. The TMDL meets the water quality standard based on the 30-day geometric mean. After the TMDL is fully implemented, the geometric mean of fecal coliform concentration over any 30-day period will not exceed 190 cfu/100 mL.
2. The TMDL was developed taking into account all fecal coliform sources (human-related and wildlife).
3. A margin of safety (MOS) of 5% was incorporated to ensure compliance of the geometric mean standard upon TMDL implementation.
4. Both high- and low-flow stream conditions were considered while developing the TMDL. In the Mill Creek watershed, low stream flow was found to be the environmental condition most likely to cause a violation of the 30-day geometric mean; however, because the TMDL was developed using a continuous simulation model, it applies to both high- and low-flow conditions.

5. Both the flow regime and fecal coliform loading to stream are seasonal, with higher loadings and in-stream concentrations during summer. The TMDL accounts for these seasonal effects.
6. The selected TMDL allocation requires a 100% reduction in direct deposits of cattle manure to streams and a 70% reduction in direct wildlife deposits to streams. Using Eq. [6.1], and based on the selected TMDL allocation scenario (Scenario 4), the fecal coliform TMDL for Mill Creek is given in Table 6.5.

**Table 6.5. Annual fecal coliform loadings (cfu/year) used for the fecal coliform TMDL for Mill Creek**

Parameter	SWLA	SLA	MOS <sup>a</sup>	TMDL
Fecal coliform	0	1597.0 × 10 <sup>12</sup>	84.0 × 10 <sup>12</sup>	1681.0 × 10 <sup>12</sup>

<sup>a</sup> Five percent of TMDL

## **7. IMPLEMENTATION**

### **7.1. Follow-up Monitoring**

The existing Mill Creek monitoring station will be maintained by VADEQ during the TMDL implementation process. The station (1BMIC001.00) was established in September of 1993. VADEQ and VADCR will continue to use data from this monitoring station for evaluating reductions in fecal bacteria counts and the effectiveness of the TMDL in attainment of water quality standards.

Monthly sampling for fecal coliform bacteria will continue at 1BMIC001.00 until the violation rate of Virginia's fecal coliform standard, 1,000 cfu/100 mL, is reduced to 10% or less. After this reduction in the fecal coliform violation rate is verified, the monitoring frequency for this parameter will be increased to two or more samples within a 30-day period. This sampling frequency is needed to provide the water quality data needed for evaluation and verification that the TMDL will attain and maintain Virginia's water quality standard, the geometric mean of 200 cfu/100 mL.

### **7.2. TMDL Implementation Process**

The goal of this TMDL is to establish a path which will lead to expeditious attainment of water quality standards. The first step in this process was to develop an implementable TMDL. The second step is to develop a TMDL implementation plan, and the final step is to implement the TMDL.

Section 303(d) of the Clean Water Act and USEPA's 303(d) regulation do not provide new implementing mechanisms for TMDL development. However, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act directs VADEQ to develop a plan for the expeditious implementation of TMDLs.

Virginia DEQ plans to incorporate TMDL implementation plans as part of the 303(e) Water Quality Management Plans (WQMP). In response to the recent USEPA/VADEQ Memorandum of Understanding, VADEQ submitted a Continuous Planning Process to USEPA in which Virginia commits to updating the WQMPs, which will be the repository



of TMDLs and the implementation plans. Each implementation plan will contain a reasonable assurance section, which will detail the availability of funds for implementation of voluntary actions.

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. In response to the federal Clean Water Action Plan, Virginia developed a Unified Watershed Assessment that identifies watershed priorities. Watershed restoration activities, such as TMDL implementation, within these priority watersheds are eligible for Section 319 funding. Increases in Section 319 funding in future years will be targeted towards TMDL implementation and watershed restoration.

Watershed stakeholders will have opportunities to provide input and to participate in development of the implementation plan, with support from regional and local offices of VADEQ, VADCR and other participating assistance agencies.

Implementation of best management practices (BMPs) in the watersheds will occur in phases. The benefit of phased implementation is that as stream monitoring continues to occur, accurate measurements of progress being achieved will be recorded. This approach provides a measure of quality control, given the uncertainties which exist in the developed TMDL model. The target for the first phase of implementation will be 10% violation of the 1,000 cfu/100 mL instantaneous standard.

### **7.3. Phase 1 Implementation Scenario**

The goal of the Phase 1 Allocation Scenario was to determine the fecal coliform loading reductions required to reduce violations of the instantaneous 1,000 cfu/100 mL water quality standard to less than 10 percent. Several scenarios reduced violations to less than 10% (Table 7.1).

The final scenario selected for Phase 1 implementation (Scenario 4) allows some access to streams by cattle. Loadings for the existing allocation and Phase 1 allocation scenario for nonpoint and direct nonpoint sources are presented in Tables 7.2 and 7.3, respectively.

No reductions in fecal coliform loadings for wildlife or nonpoint sources are required to achieve the less than 10% of the 1,000 cfu/100mL goal. Fecal coliform concentrations resulting from Scenario 4 are presented graphically in Figure 7.1.

**Table 7.1. Allocation scenarios for Phase 1 TMDL implementation for Mill Creek**

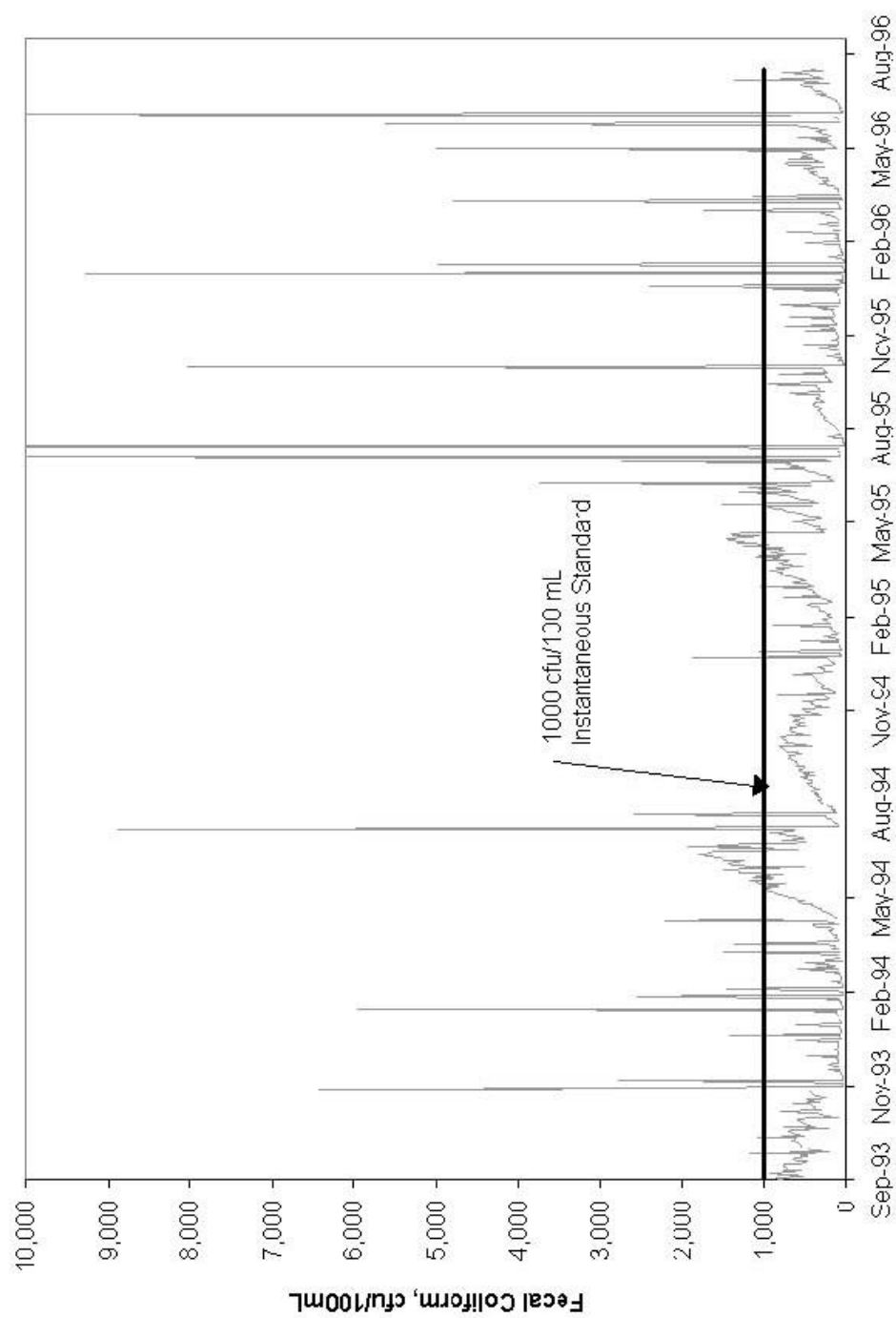
Scenario Number	Percent reduction in loading from existing condition				
	Direct wildlife deposits	Direct cattle deposits	NPS from pervious land segments	NPS from impervious land segments	Percentage of days with FC conc > 1,000 cfu/100mL
<b>1</b>	0%	100	100	100	0.0
<b>2</b>	0%	94	0	0	15.0
<b>3</b>	0%	97	0	0	8.4
<b>4</b>	<b>0%</b>	<b>96.5</b>	<b>0</b>	<b>0</b>	<b>9.4</b>

**Table 7.2. Annual nonpoint source load reductions for Phase 1 TMDL implementation scenario (Scenario 4)**

Land-use Category	Existing conditions		Allocation scenario	
	Existing load ( $\times 10^{12}$ cfu)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load ( $\times 10^{12}$ cfu)	Percent reduction from existing load
<b>Cropland</b>	77.8	4.9	77.8	0.0
<b>Pasture 1</b>	1307.8	82.0	1307.8	0.0
<b>Pasture 2</b>	110.7	6.9	110.7	0.0
<b>Pasture 3</b>	48.0	3.0	48.0	0.0
<b>Farmstead</b>	2.7	0.2	2.7	0.0
<b>Rural Residential</b>	32.2	2.0	32.2	0.0
<b>Urban Residential</b>	10.6	0.7	10.6	0.0
<b>Loafing Lot</b>	0.1	<.01	0.1	
<b>Forest</b>	3.9	0.2	3.9	0.0
<b>Total</b>	<b>1,593.8</b>	<b>100.0</b>	<b>1,593.8</b>	<b>0.0</b>

**Table 7.3. Required direct nonpoint source load reductions for Phase 1 Implementation Scenario (Scenario 4).**

<b>Source</b>	<b>Existing conditions load (<math>\times 10^{12}</math> cfu)</b>	<b>Percent of total load to stream from direct nonpoint sources</b>	<b>TMDL direct nonpoint source allocation load (<math>\times 10^{12}</math> cfu)</b>	<b>Percent reduction from existing loads</b>
<b>Cattle in Streams</b>	133.5	92.5	4.7	96.5
<b>Wildlife in Streams</b>	10.8	7.5	10.8	0.0
<b>Total</b>	<b>144.3</b>	<b>100.0</b>	<b>15.5</b>	<b>89.3</b>



**Figure 7.1. Phase 1 TMDL implementation scenario for Mill Creek**

## **7.4. Wildlife and Water Quality Standards**

### **7.4.1. Wildlife Contributions**

VADEQ and VADCR have developed fecal coliform TMDLs for a number of impaired waters in the State. In some of the streams, fecal coliform bacteria counts contributed by wildlife result in standards violations, particularly during base flow conditions. Wildlife densities obtained from the Department of Game and Inland Fisheries and analysis or “typing” of the fecal coliform bacteria show that the high densities of muskrat, beaver, and waterfowl are responsible for the elevated fecal bacteria counts in these streams. In order to address this issue, the Commonwealth is currently reviewing its water quality standards with respect to fecal coliform bacteria. The issues under review are 1) designated uses, 2) indicator species, and 3) applicable flow conditions. Another option that EPA allows for the states is to adopt site specific criteria based on natural background levels of fecal coliforms. The State must demonstrate that the source of fecal contamination is natural and uncontrollable by effluent limitations and BMPs.

### **7.4.2. Designated Use**

All waters in the Commonwealth have been designated as "primary contact" for the swimming use regardless of size, depth, location, water quality or actual use. The fecal coliform bacteria standard is described in 9 VAC 25-260-170 and on page 1–3 in Section 1 of this report. This standard is to be met during all stream flow levels and was established to protect bathers from ingestion of potentially harmful bacteria. However, many headwater streams are small and shallow during base flow conditions when surface runoff has minimal influence on stream flow. Even in pools, these shallow streams do not allow full body immersion during periods of base flow. In larger streams, lack of public access often precludes the swimming use.

Base flow conditions of a stream occur at a higher frequency than flow conditions influenced by precipitation runoff events. As a result, the vast majority of the water quality sampling in the watershed used to determine the impairment occurred during base flow conditions. Therefore, a critical period for modeling to insure the attainment of water quality standards is during base flow conditions with little or no storm runoff.

In the TMDL public participation process, the residents in these watersheds often report that " people do not swim in this stream." It is obvious that many streams within the state are not used for recreational purposes. In many cases, insufficient depth of the streams along with other physical factors and lack of public accessibility do not provide suitable conditions for swimming or primary contact recreation.

#### **7.4.3. TMDL Allocations**

The wildlife contributions of fecal bacteria from muskrats, beavers, and waterfowl are at their highest counts during base flow conditions when there is little or no pollutant wash-off from the adjacent land areas. Therefore base flow events represent the critical condition because the allocations needed to attain water quality standards during these flow regimes insure that standards were met in all other flow ranges.

For many of these streams, even the removal of all of the sources of fecal coliform (other than wildlife) does not allow the stream to attain standards during these critical conditions (or low flows). TMDL allocation reductions of this magnitude are not realistic and do not meet EPA's guidance for reasonable assurance. Based on the water quality modeling, many of these streams will not be able to attain standards without some reduction in wildlife. Virginia and EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards. This is obviously an impractical action. Clearly, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL or any other federal and state water quality management programs.

#### **7.4.4. Options for Resolution of Wildlife Problem**

To address the wildlife problem, EPA and Virginia have developed a TMDL strategy that will provide the reasonable assurance necessary under EPA guidance. The first step in this strategy is to develop a phased approach for the attainment of water quality standards in the TMDL. The first phase is to select an interim reduction goal, such as the Stage I implementation target described above. This goal has been selected by the stakeholders in the watershed and Virginia for EPA's approval as part of the TMDL process. In the interim goal or target, the pollutant reductions contained in the allocation

were made only on controllable sources identified in the TMDL, setting aside any reduction of wildlife. During the first phase, all reductions from controllable sources called for in the TMDL allocation would be reduced to their appropriate levels. The first phase would be a labor-intensive process that could occur on an incremental basis. While the first phase is underway, Virginia would be working concurrently on the second phase to address the wildlife issue.

Following completion of the first phase reductions, the VADEQ would re-assess the streams to determine if water quality standards had been attained. This effort will also determine if the modeling assumptions and approaches are correct. If it were found that water quality standards are not met, the second phase allocations would be initiated at a level necessary to meet existing standards. In some cases, the effort may never have to go to the second phase.

The second phase of the TMDL will address the issues associated with the water quality standard. This phase involves a number of components as outlined below:

1. EPA has recommended that all States adopt an *E. coli* or enterococci standard for fresh water and enterococci criteria for marine waters by 2003. EPA is pursuing the States' adoption of these standards because there is a stronger correlation between the concentration of these organisms (*E. coli* and enterococci) and the incidence of gastrointestinal illness than with fecal coliform. *E-coli* and enterococci are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination. The adoption of the *E. coli* and enterococci standard is scheduled for 2002 in Virginia.

2. Recognizing that all waters in the Commonwealth are not used extensively for swimming, VA is currently looking at re-designation of the swimming use based on actual swimming frequency and risk assessment. The new designation of the swimming use could contain the following 4 levels:

- Designated bathing beach (currently all waters protected to this level),
- Moderate swimming,
- Low swimming, and
- Infrequent swimming.

Each of the four swimming use levels would have protection criterion based on risk analysis. The current high levels of protection would continue to be applied to waters in which people are more likely to engage in an activity that results in the ingestion of water. The primary contact recreational uses recommended above are from EPA's Ambient Water Quality Criteria for Bacteria, 1986.

3. The re-designation of the current swimming use may require the completion of a use attainability analysis. A Use Attainability Analysis (UAA), is a structured scientific assessment of the factors affecting the attainment of the use which may include physical, chemical, biological, and economic factors as described in the Federal Regulations. The stakeholders in the watershed, Virginia, and EPA will have an opportunity to comment on these special studies.

4. Most states apply their water quality standards only to flows above a statistical low flow frequency that is defined as the lowest flow occurring for seven consecutive days once every 10 years (7Q10). However, Virginia's fecal coliform bacteria standard is applied to all flows. Some head water streams have very minimal flow during periods of low precipitation or droughts. During such low flow events, the counts of fecal coliform bacteria deposited directly into the stream are concentrated because the small flow is unable to dilute the deposition of wastes. In order to attain standards during low flow conditions, it is necessary to reduce the amount of waste deposited directly to the stream. Sources of these wastes include cattle in-stream, wildlife in-stream, septic systems, and wastes conveyed directly to the stream from milking parlors. By applying the standard only to flows greater than 7Q10, the TMDL would not need to insure the attainment of standards during extreme drought flow conditions when stream flow falls below 7Q10.



## **8. PUBLIC PARTICIPATION**

The first public meeting, held in Dayton, VA on 9 December 1999 to discuss the development of the TMDL, was public noticed on 3 November 1999 in the Virginia Register. Letters announcing the meeting were also sent to stakeholders in the watersheds, including the Shenandoah Pure Water 2000 Forum, the Friends of the North River, the VA State Dairymen's Association, the VA Poultry Federation, the Rockingham Farm Bureau, the Rockingham County Administrator and the Rockingham County Planning Director. Copies of the presentation materials and diagrams outlining the development of the TMDL were available for public distribution at the meeting. Approximately 12 people attended the meeting. The public comment period ended on 21 January 2000. A summary of the questions and answers discussed at the meeting was prepared and is located at the VADEQ Valley Regional Office in Harrisonburg, VA.

The second public meeting, held in Dayton, VA on 20 January 2000 to discuss the hydrologic calibration and input data for the TMDL, was public noticed on 14 December, 1999 in the Virginia Register. Copies of the presentation materials and of the Q&A summary from the previous meeting were available for public distribution at the meeting. Approximately 10 people attended the meeting. The public comment period ended on 21 February 2000. A summary of the questions and answers discussed at the meeting was prepared and is located, together with subsequently received written comments, at the VADEQ Valley Regional Office in Harrisonburg, VA.

The third public meeting, held in Dayton on 28 March 2000 to discuss the draft TMDL, was public noticed on 13 March 2000 in the Virginia Register. Copies of the draft TMDL were available for public distribution at the time of public notice and at the meeting. Approximately 50 people attended the meeting. The public comment period ended on 11 April 2000. No written comments were submitted.

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## **GLOSSARY**

### **Allocation**

That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources.

### **Allocation Scenario**

A proposed series of point and nonpoint source allocations (loadings from different sources), which are being considered to meet a water quality planning goal.

### **Background levels (of fecal coliform)**

Natural pollutant levels due to wildlife

### **BASINS (Better Assessment Science Integrating Point and Nonpoint Sources)**

A computer-run tool that contains an assessment and planning component that allows users to organize and display geographic information for selected watersheds. It also contains a modeling component to examine impacts of pollutant loadings from point and nonpoint sources and to characterize the overall condition of specific watersheds.

### **Best Management Practices (BMP)**

Methods, measures, or practices that are determined to be reasonable and cost-effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

### **Calibration**

The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

### **Die-off (of fecal coliform)**

Reduction in the fecal coliform population due to predation by other bacteria as well as by adverse environmental conditions (e.g., UV radiation, pH)

### **Direct nonpoint sources**

Sources of pollution that are defined statutorily (by law) as nonpoint sources that are represented in the model as point source loadings in the model due to limitations of the model. Examples include: direct deposits of fecal material to streams from livestock and wildlife.

**E-911 digital data**

Emergency response database prepared by the county that contains graphical data on road centerlines and buildings. The database contains approximate outlines of buildings, including dwellings and poultry houses.

**Failing septic system**

Septic systems in which drain fields have failed such that effluent (wastewater) that is supposed to percolate into the soil, now rises to the surface and ponds on the surface where it can flow over the soil surface to streams or contribute pollutants to the surface where they can be lost during storm runoff events.

**Fecal coliform**

A type of bacteria found in the feces of various warm-blooded animals that is used as indicator of the possible presence of pathogenic (disease causing) organisms.

**Geometric mean**

The geometric mean is simply the  $n$ th root of the product of  $n$  values. Using the geometric mean, lessens the significance of a few extreme values (extremely high or low values). In practical terms, this means that if you have just a few bad samples, their weight is lessened. Mathematically the geometric mean,  $\bar{x}_g$ , is expressed as:

$$\bar{x}_g = \sqrt[n]{x_1 \times x_2 \times \dots \times x_n}$$

where  $n$  is the number of samples, and  $x_i$  is the value of sample  $i$ .

**HSPF (Hydrological Simulation Program-Fortran)**

A computer-based model that calculates runoff, sediment yield, and fate and transport of various pollutants to the stream. The model was developed under the direction of the U.S. Environmental Protection Agency (EPA).

**Hydrology**

The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

**Instantaneous criterion**

The instantaneous criterion or instantaneous water quality standard is the value of the water quality standard that should not be exceeded at any time. For example, the Virginia instantaneous water quality standard for fecal coliform is 1,000 cfu/100 mL. If this value is exceeded at any time, the water body is in violation of the state water quality standard.

**Load allocation (LA)**

The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background.

**Margin of Safety (MOS)**

A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models). The MOS may also be assigned explicitly, as was done in this study, to ensure that the water quality standard is not violated.

**Model**

Mathematical representation of hydrologic and water quality processes. Effects of land-use, slope, soil characteristics, and management practices are included.

**Nonpoint source**

Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

**Pathogen**

Disease-causing agent, especially microorganisms such as bacteria, protozoa, and viruses.

**Point source**

Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

**Pollution**

Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

**Reach**

Segment of a stream or river.

**Runoff**

That part of rainfall or snowmelt that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

**Septic system**

An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a system of tile lines or a pit for disposal of the liquid effluent (sludge) that remains after decomposition of the solids by bacteria in the tank; must be pumped out periodically.

**Simulation**

The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified are then used to predict the response of a natural water system to changes in the input or forcing conditions.

**Straight pipe**

Delivers wastewater directly from a building, e.g., house, milking parlor, to a stream, pond, lake, or river.

**Total Maximum Daily Load (TMDL)**

The sum of the individual wasteload allocations (WLA's) for point sources, load allocations (LA's) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

**Urban Runoff**

Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

**Validation (of a model)**

Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical process under investigation.

**Wasteload allocation (WLA)**

The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation.

**Water quality standard**

Law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an anti-degradation statement.

**Watershed**

A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.



## **APPENDIX A**

**Sample Calculation: distribution of Dairy Cattle in MLC-B during January**

### Sample calculation: distribution of dairy cattle in MLC-B during January

(Note: Due to rounding, the numbers may not add up.)

1. Breakdown of the dairy herd as presented in Sec. 4.2.1 is 42% milk cows, 8% dry cows, and 50% heifers.

Dairy cattle population	=		260.0
Milk cow population	=	$260.0 * (42\%)$	= 109.2
Dry cow population	=	$260.0 * (8\%)$	= 20.8
Heifer population	=	$260.0 * (50\%)$	= 130.0

2. During January, milk cows, dry cows, and heifers are confined 75, 40, and 40% of the time, respectively (Table 4.3)

Milk cows in confinement	=	$109.2 * (75\%)$	= 81.9
Dry cows in confinement	=	$20.8 * (40\%)$	= 8.3
Heifers in confinement	=	$130.0 * (40\%)$	= 52.0
All dairy cows in confinement	=	$81.9 + 8.3 + 52.0$	= 142.2

3. When not confined, milk cows spend 25% time in the loafing lot. However, since there are no loafing lots in MLC-B (Table 4.2), no milk cows are present in the loafing lot. Dry cows and heifers do not have access to loafing lot.

$$\text{Milk cows in loafing lot} = (109.2 - 81.9) * (25\%) * (0/2) = 0.0$$

4. Cattle in pastures and stream are calculated by subtracting cattle in confinement (Step 2) and in loafing lots (Step 3) from total cattle population (Step 1).

Milk cows on pastures and streams	=	$109.2 - 81.9 - 0.0$	= 27.3
Dry cows on pastures and streams	=	$20.8 - 8.3$	= 12.5
Heifers on pastures and streams	=	$130.0 - 52.0$	= 78.0

5. Total pasture acreage is 251.3 acres with pastures 1, 2, and 3 occupying 90.0%, 6.9%, and 3.1%, respectively (Table 3.2). The stocking densities in pastures 1, 2, and 3 are 1, 2, and 4, respectively (Sec. 4.2.1). Based upon the stocking density, relative stocking densities in pastures 1, 2, and 3 are 1/7, 2/7, and 4/7, respectively.

$$\begin{aligned} \text{Percent cattle in all pasture 1} \\ = (90.0\%) * (1/7) / [(90\%) * (1/7) + (6.9\%) * (2/7) + (3.1\%) * (4/7)] &= 77.4 \end{aligned}$$

$$\begin{aligned} \text{Percent cattle in all pasture 2} \\ = (6.9\%) * (2/7) / [(90\%) * (1/7) + (6.9\%) * (2/7) + (3.1\%) * (4/7)] &= 11.9 \end{aligned}$$

$$\begin{aligned} \text{Percent cattle in all pasture 3} \\ = (3.1\%) * (4/7) / [(90\%) * (1/7) + (6.9\%) * (2/7) + (3.1\%) * (4/7)] &= 10.7 \end{aligned}$$

6. Percentage acreage of pastures 1, 2, and 3 with access to stream are 19.5%, 77.18%, and 0.0%, respectively (Table 4.4). Use the percent cattle in each pasture (step 5) to estimate percent cattle with access to stream:

$$[(77.4\% \times 19.5\%) + (11.9\% \times 77.1\%) + (10.7\% \times 0.0\%)] = 24.3\%$$

7. Cattle with access to streams are calculated as follow.

$$\text{Milk cows on pastures with stream access} = 27.3 \times 24.3\% = 6.6$$

$$\text{Dry cows on pastures with stream access} = 12.5 \times 24.3\% = 3.0$$

$$\text{Heifers on pastures with stream access} = 78.0 \times 24.3\% = 19.0$$

8. Numbers of cattle in and around streams is calculated by multiplying cattle on pasture with stream access with the number of hours each cattle spends in the stream (Table 4.3). Cattle with stream access calculated in Step 7 are required.

$$\text{Milk cows in and around streams} = 6.6 \times (0.5/24) = 0.1$$

$$\text{Dry cows in and around streams} = 3.0 \times (0.5/24) = 0.1$$

$$\text{Milk cows in and around streams} = 19.0 \times (0.5/24) = 0.4$$

9. Number of cattle defecating in the stream is calculated by multiplying the number of cattle in and around the stream by 30% (Sec. 4.2.1). Cattle in and around stream calculated in Step 8 are required.

$$\text{Milk cows defecating in streams} = 0.1 \times 30\% = 0.0$$

$$\text{Dry cows defecating in streams} = 0.1 \times 30\% = 0.0$$

$$\text{Heifers defecating in streams} = 0.4 \times 30\% = 0.1$$

10. After calculating the number of cattle defecating in the stream, the number of cattle defecating on the pastures is calculated by subtracting the number of cattle defecating in the stream (Step 9) from number of cattle in pasture and stream (Step 4). To obtain the number of cattle in each pasture category, the number of cattle in all pastures is multiplied by the percent of cattle in that pasture category (Step 5).

$$\text{Milk cows defecating on pasture 1} = (27.3 - 0.0) \times 77.4\% = 21.1$$

$$\text{Milk cows defecating on pasture 2} = (27.3 - 0.0) \times 11.9\% = 3.3$$

$$\text{Milk cows defecating on pasture 3} = (27.3 - 0.0) \times 10.9\% = 2.9$$

$$\text{Dry cows defecating on pasture 1} = (12.5 - 0.0) \times 77.4\% = 9.7$$

$$\text{Dry cows defecating on pasture 2} = (12.5 - 0.0) \times 11.9\% = 1.5$$

$$\text{Dry cows defecating on pasture 3} = (12.5 - 0.0) \times 10.9\% = 1.3$$

$$\text{Heifers defecating on pasture 1} = (78.0 - 0.1) \times 77.4\% = 60.4$$

$$\text{Heifers defecating on pasture 2} = (78.0 - 0.1) \times 11.9\% = 9.3$$

$$\text{Heifers defecating on pasture 3} = (78.0 - 0.1) \times 10.9\% = 8.2$$

## **APPENDIX B**

### **Weather Data Preparation**

## Weather Data Preparation

### Summary

A weather data file for providing the weather data inputs into the HSPF Model was created for the period September 1984 through July 1996 using the WDMUtil. Raw data required for creating the weather data file included hourly precipitation (in.), average daily temperatures (maximum, minimum, and dew point) (°F), average daily wind speed (mi./h), total daily solar radiation (langleys), and percent sun. The primary data source was the National Climatic Data Center's (NCDC) Cooperative Weather Station at Dale Enterprise, Rockingham Co., Virginia; data from three other NCDC stations were also used. Daily solar radiation data was generated using CLIGEN<sup>1</sup>. The raw data required varying amounts of preprocessing prior to input into WDMUtil or within WDMUtil to obtain the following hourly values: precipitation (PREC), air temperature (ATEM), dew point temperature (DEWP), solar radiation (SOLR), wind speed (WIND), potential evapotranspiration (PEVT), potential evaporation (EVAP), and cloud cover (CLOU). The final WDM file contained the above hourly values as well as the raw data. The raw data were retained in the WDM file since WDMUtil does not have provision for deleting such data; such data can only be overwritten.

### Raw data collection and processing

Weather data in the variable length format were obtained from the NCDC's weather stations in Dale Enterprise, VA (Lat./Long. 38.5N/78.9W, elevation 1400 ft); Timberville, VA (Lat./Long. 38.7N/78.7W, elevation 1001 ft); Lynchburg Airport, VA (Lat./Long. 37.3N/79.2W, elevation 940 ft); and Elkins Airport, WV (Lat./Long. 38.9N/79.9W, elevation 1948 ft). While deciding on the period of record for the weather WDM file, availability of flow and water quality data was considered in addition to the availability and quality of weather data. While data for all other parameters were available for the September 1984 through December 1997 period, percent sun data were only available until July 1996. Hence, the weather WDM file was prepared for the September 1984 through July 1996 period. In the following pages, the procedures used to process the raw data to obtain finished data required for preparing the WDM file are described.

#### 1. Hourly precipitation

Hourly precipitation (PREC) data were purchased from the NCDC for Dale Enterprise for the period 1984 through 1998 in variable length format. Data in variable length format became available free of cost online beginning mid-November, 1999. The file obtained from NCDC required modifications before it could be read by WDMUtil. First, the first four columns in each line that indicated the line width were removed with a text editor. Second, the unit of the PREC depth was changed to HI

(hundredths of an inch) from HT (Note: the file should have the correct units in at least the first line of record). Finally, the file was renamed as an NCD file and was successfully read by WDMUtil.

The PREC record for the September 1984 through July 1996 period (4352 days) was missing 220 days of hourly precipitation data. Daily precipitation (PRECD) data collected by the NCDC's weather station at Dale Enterprise obtained for that period, was reported as the total depth of precipitation occurring during the past 24 hours as reported at 7 a.m.

The possibility of using a precipitation disaggregation program was considered. Such programs require a complete hourly record for a neighboring (template) station in addition to PRECD for the site. The station closest to Dale Enterprise collecting hourly precipitation data is the Staunton Sewage Plant (SSP) (Lat./Long. 38.2N/79.1W, elevation 1640 ft) located 21 miles to the south of Dale Enterprise. However, since the SSP data had missing records for many months, this option was discarded. Hence, the following options were used to fill in the missing hourly data.

- a) Daily precipitation depth measured at Dale Enterprise was disaggregated into hourly values based on the hourly precipitation distribution observed at the SSP.
- b) However, there were precipitation events in Dale Enterprise, as observed in the PRECD record that, either did not occur in SSP or the SSP records were missing for those periods. The following steps were taken to disaggregate such precipitation events.
  - (i) If the total depth of precipitation was less than or equal to 0.2 in., the entire event was assumed to have occurred during the 6:00-7:00 p.m. hour of the previous day.
  - (ii) For PRECD greater than 0.2 in., the raw PREC data file for DE was examined for that day (Note: If the raw PREC data is missing even 1 h of data as indicated by a missing depth value and an incomplete daily depth, WDMUtil will report a day with missing data). If no more than 2 h of data were missing, the difference between PRECD depth and the total incomplete depth record was assigned equally to the missing hours or in full if only one hour of data was missing.
  - (iii) When PRECD exceeded 0.2 in. and raw PREC data file for DE indicated more than 2 h of missing data, the flow observed in Linville Creek was considered for disaggregating daily into hourly precipitation values. The flow data for Linville Creek data was used because it provided the longest period of record compared with flow records for other streams in that area. Since the flow data also account for watershed response to previous events and seasonality (e.g., thunderstorms), such an approach was considered to be appropriate.

Table B.1 provides a summary of the number of days when either option a or b was used. For those days when there were multiple precipitation events and when the same option could not be applied to all the events, multiple options were used (Note: no more than two options were used on a single day). For such days, the option used for the greater precipitation depth is listed.

**Table B.1. Summary of number of days requiring disaggregation or no disaggregation**

Option	Number of days
Option a: Used SSP PREC as a guide to disaggregate DE PRECD	143
Option b(i): For events = 0.2 in., assigned to single hour	31
Option b(ii): Used raw PREC data and PRECD data	21
Option b(iii): Used flow data	25
No processing required	4132

2. Temperature

Separate daily maximum temperature (TMAX) and daily minimum temperature (TMIN) files in variable length format were obtained from NCDC. Spurious data fields (e.g., 32 data fields for a month with 31 days) tagged in the TMAX variable length format file, were deleted. The TMAX data file had six days of missing data. The TMIN file did not have missing values. Both the TMAX and TMIN values for the six days were filled in with Timberville data. In each file (TMAX or TMIN), the first four columns in each line were deleted and the modified file was saved as an NCD file. Since daily average dew point temperature (DPTP) is not measured at Dale Enterprise, TMIN was used as DPTP, as recommended in the BASINS documentation. The TMIN NCD file was modified by replacing TMIN by DPTP and saved as a DPTP NCD file. All three files (TMAX, TMIN, and DPTP) were successfully read into WDMUtil. The DISAGGREGATE function in WDMUtil was used to develop hourly air temperature (ATEM) for the modeling period from TMAX and TMIN. Similarly, the DISAGGREGATE function was used to calculate hourly dew point temperature (DEWP) from DPTP.

3. Average daily wind speed

Since average daily wind speed (DWND) is not measured by the NCDC's weather station at Dale Enterprise, DWND data was obtained for NCDC's station at Elkins Airport, the closest location to Dale Enterprise where DWND is recorded. The variable length format file received from NCDC gave average daily wind speed in TL (tenths of mi./h). Since the file also contained the units of TK (tenths of knot/h), the file required modification to express the units only in TL. Also, editing was performed to remove one spurious data field. However, it was observed that WDMUtil read the file as mi./h and not as tenths of mi./h. Hence, the file read as mi./h was saved as a

text file in WDMUtil. The text file was opened in EXCEL. The values were converted to mi./d and the date field was modified to have four-digit years (mm/dd/yyyy); WDMUtil cannot read a date field with a two-digit year. The resulting file was saved as an ASCII flat file. A flat file cannot be created from the NCD file and considerable preprocessing is required if the WDMUtil is not used. The flat file was read back into WDMUtil to obtain DWND in mi/d. The DISAGGREGATE function in WDMUtil was used to obtain hourly wind speed (WIND) in mi/h.

4. Total daily solar radiation (DSOL)

Solar radiation data is not collected at Dale Enterprise. Initially, it was proposed to use measured percent sun data for Elkins Airport (WV) to calculate DSOL; there were no other sites within a 100-mile radius of Dale Enterprise with solar radiation data. However, since DSOL record for Elkins Airport was only available until May 1994, synthetic DSOL was generated for Monterey, VA (Lat./ Long. 38.4N/79.6W, elevation 2950 ft) using CLIGEN in the WEPP input format. The resulting file was processed in EXCEL to obtain a text file with one column of days and another column of total daily solar radiation (Iy) and with a date field with four-digit years. The modified DSOL text file was successfully read into WDMUtil. The DISAGGREGATE function in WDMUtil was used to obtain hourly solar radiation (SOLR).

5. Percent sun (PSUN)

In the absence of daily cloud cover (DCLO), PSUN can be used to estimate DCLO. DCLO in turn is used by WDMUtil to estimate hourly cloud cover (CLOU) in tenths. An extensive search of the NCDC archive for locations as far away as Beltsville, MD (about 118 mi from DE) failed to provide DCLO, PSUN, or CLOU data more recent than July 1996. Hence, it was decided to use data for the period September 1984 through July 1996 from Lynchburg Airport in the following order of preference – CLOU, DCLO, and PSUN. Since CLOU was unavailable and DCLOU data had missing records, PSUN in the variable length format, obtained from the NCDC was used. The first four columns in each line of the PSUN file was deleted in a text editor and the resulting file was saved as an NCD file.

A new WDM file was created and the PSUN NCD file was read into it. The COMPUTE function in WDMUtil was used to calculate DCLO (in percent) from PSUN. The resulting DCLO file was saved as a text file. The DCLO text file was opened in EXCEL and the date field was formatted (mm/dd/yy) and the DCLO value was converted from percent to tenths (e.g., 50%  $\equiv$  5). The text file was further modified in a text editor to create a four-digit year field. The final DCLO flat file was read into WDMUtil. The final WDM file that contains all hourly and daily data does not contain PSUN. The DISAGGREGATE function used for disaggregating DWND to WIND was used to disaggregate DCLO into CLOU with all hourly coefficients being set equal to one. The choice of one as the coefficient for all hours in a day



resulted in all CLOU values for a day being equal to DCLO value for that day. No separate DISAGGREGATE function is available for CLOU as there are for ATEM, DEWP, SOLR, WIND, and daily potential evapotranspiration (PEVT).

#### **Input data and processing in WDMUtil required for HSPF input parameters**

The input data and WDMUtil processing required for calculating hourly weather data required for use in HSPF are discussed above. Other parameters such as hourly Penman pan (potential) evaporation (EVAP) and hourly potential evapotranspiration (PEVT) require more than one type of input data. Table B.2 summarizes all the parameters that are required in modeling in HSPF as well as the inputs and methods required for calculating the parameters.

**Table B.2. Weather parameters and processing in WDMUtil required for HSPF modeling**

<b>Input parameters</b>	<b>WDMUtil functions</b>	<b>HSPF parameter</b>
PREC	No further processing required	PREC
TMAX and TMIN	DISAGGREGATE	ATEM
DPTP	DISAGGREGATE	DEWP
DSOL	DISAGGREGATE	SOLR
DWND	COMPUTE	WIND
TMAX and TMIN DEVT	COMPUTE DISAGGREGATE	DEVT (Hamon) <sup>a</sup> PEVT
TMAX, TMIN, DPTP, DWND, DSOL DEVP	COMPUTE DISAGGREGATE <sup>b</sup>	DEVP (Penman) <sup>a</sup> EVAP
PSUN DCLOU	COMPUTE DISAGGREGATE <sup>c</sup>	DCLOU <sup>a</sup> CLOU

<sup>a</sup> Parameters not required by HSPF

<sup>b</sup> DISAGGREGATE function for DEVT used

<sup>c</sup> DISAGGREGATE function for DWND used

<sup>1</sup>CLIGEN – Climatic Generator, a program used to generate weather parameters using historic data

## **APPENDIX C**

### **Die-off of Fecal Coliform during Storage**

## Die-off of Fecal Coliform during Storage

The following procedure was used to calculate amount of fecal coliform produced in confinement in different types of waste applied to cropland and pasture. All calculations were performed on spreadsheet (one for each subwatershed).

1. Fifty percent dairy farms have liquid manure storage for 90 days while 20% have 180-day storage capacity (VADCR, 1999). The remaining dairy farms have bedding storage capacity of 120 days (VADCR, 1999). Using decay rates of 0.375 and 0.05 (Table 5.2) for liquid and bedding storages, the die-off of fecal coliform in different storage capacities at the ends of the respective storage periods were calculated using Eq. [5.1]. Based on the fractions of different storage capacities, a weighted average die-off was calculated for all liquid dairy manure that also included bedding storage.

Virginia DCR (1999) reported that average storage capacities for both solid manure and poultry litter was 120 days. Hence, fecal coliform die-off values in solid manure and poultry litter storages at the end of 120 days were calculated using decay rates of 0.05 (solid manure) and 0.035 (poultry litter) (Table 5.2).

2. Based on fecal coliform die-off, the surviving fraction of fecal coliform at the end of storage period was estimated separately for liquid manure, solid manure, and poultry litter. The surviving fractions of fecal coliform in liquid manure, solid manure, and poultry litter were 0.035, 0.068, and 0.099, respectively.
3. The annual production of fecal coliform based on 'as-excreted' values (Table 3.3) was calculated for separately for liquid manure, solid manure, and poultry litter. For poultry litter, the fecal coliform produced per annum was based on the relative contributions of layers, broilers, and turkeys.
4. The annual fecal coliform production from a source (e.g., liquid manure) was multiplied by the fraction of surviving fecal coliform in that source to obtain the amount of fecal coliform that was available for land application on annual basis. For monthly application, the annual figure was multiplied by the fraction of waste applied during that month based on the application schedule given in Table 4.7.

## **APPENDIX D**

### **Fecal Coliform Loading in Subwatersheds of Mill Creek**

**Table D.1. Monthly nonpoint fecal coliform loadings to the different land-use categories in the subwatershed MLC-A of the Mill Creek watershed**

Month	Fecal coliform loadings ( $\times 10^9$ cfu/month)								
	Crop-land	Pasture 1	Pasture 2	Pasture 3	Rural Resid-entia	Farm-stead	Urban Resid-entia	Loafing lot	Forest
Jan.	0	32,856	5,263	2,655	739	739	0	0	17
Feb.	1,780	30,736	4,923	2,483	691	691	0	0	16
Mar.	8,898	54,596	8,751	4,415	739	739	0	0	17
Apr.	7,118	52,747	8,455	4,266	715	715	0	0	17
May	1,780	54,323	8,707	4,393	739	739	0	0	17
Jun.	0	54,071	8,314	4,195	715	715	0	0	17
Jul.	0	55,800	8,591	4,334	739	739	0	0	17
Aug.	0	55,800	8,591	4,334	739	739	0	0	17
Sep.	0	56,980	8,427	4,252	715	715	0	0	17
Oct.	2,709	54,505	8,737	4,408	739	739	0	0	17
Nov.	2,709	52,835	8,469	4,273	715	715	0	0	17
Dec.	0	32,856	5,263	2,655	739	739	0	0	17
<b>Total</b>	24,992	588,106	92,490	46,663	8,724	8,724	0	0	203

**Table D.2. Monthly nonpoint fecal coliform loadings to the different land-use categories in the subwatershed MLC-B of the Mill Creek watershed**

Month	Fecal coliform loadings ( $\times 10^9$ cfu/month)								
	Crop-land	Pasture 1	Pasture 2	Pasture 3	Rural Residential	Farmstead	Urban Residential	Loafing lot	Forest
Jan.	0	174,518	26,859	23,662	6,873	6,873	0	0	116
Feb.	9,983	163,258	25,126	22,135	6,430	6,430	0	0	109
Mar.	49,915	299,898	46,185	40,699	6,873	6,873	0	0	116
Apr.	39,932	295,066	45,441	40,044	6,651	6,651	0	0	112
May	9,983	304,438	46,884	41,316	6,873	6,873	0	0	116
Jun.	0	305,779	45,095	39,739	6,651	6,651	0	0	112
Jul.	0	314,358	46,598	41,063	6,873	6,873	0	0	116
Aug.	0	314,949	46,598	41,063	6,873	6,873	0	0	116
Sep.	0	319,945	45,372	39,983	6,651	6,651	0	0	112
Oct.	14,832	304,902	46,956	41,379	6,873	6,873	0	0	116
Nov.	15,195	290,224	44,695	39,386	6,651	6,651	0	0	112
Dec.	0	174,518	26,859	23,662	6,873	6,873	0	0	116
<b>Total</b>	139,842	3,261,853	492,668	434,128	81,148	81,148	0	0	1,370

**Table D.3. Monthly nonpoint fecal coliform loadings to the different land-use categories in the subwatershed MLC-C of the Mill Creek watershed**

Month	Fecal coliform loadings ( $\times 10^9$ cfu/month)								
	Crop-land	Pasture 1	Pasture 2	Pasture 3	Rural Residential	Farmstead	Urban Residential	Loafing lot	Forest
Jan.	0	315,116	54,748	6,331	7,505	7,505	0	0	174
Feb.	11,796	294,786	51,216	5,923	7,021	7,021	0	0	163
Mar.	58,980	524,575	91,177	10,546	7,505	7,505	0	0	174
Apr.	47,184	507,476	88,205	10,202	7,263	7,263	0	0	169
May	11,796	524,025	91,082	10,535	7,505	7,505	0	0	174
Jun.	0	520,318	87,897	10,167	7,263	7,263	0	0	169
Jul.	0	537,174	90,827	10,506	7,505	7,505	0	0	174
Aug.	0	537,174	90,827	10,506	7,505	7,505	0	0	174
Sep.	0	536,351	88,144	10,195	7,263	7,263	0	0	169
Oct.	17,955	524,392	91,146	10,542	7,505	7,505	0	0	174
Nov.	17,955	507,653	88,236	10,206	7,263	7,263	0	0	169
Dec.	0	315,116	54,748	6,331	7,505	7,505	0	0	174
<b>Total</b>	165,667	5,644,155	968,254	111,991	88,606	88,606	0	0	2,058

**Table D.4. Monthly nonpoint fecal coliform loadings to the different land-use categories in the subwatershed MLC-D of the Mill Creek watershed**

Month	Fecal coliform loadings ( $\times 10^9$ cfu/month)								
	Crop-land	Pasture 1	Pasture 2	Pasture 3	Rural Residential	Farmstead	Urban Residential	Loafing lot	Forest
Jan.	0	63,447	85,894	47,365	1,882	1,882	0	1,465	213
Feb.	5,324	59,354	80,353	44,309	1,761	1,761	0	1,370	199
Mar.	26,621	106,431	144,183	79,534	1,882	1,882	0	3,515	156
Apr.	21,297	103,341	139,997	77,225	1,821	1,821	0	3,969	151
May	5,324	106,368	144,097	79,487	1,882	1,882	0	4,101	156
Jun.	0	108,123	137,259	75,714	1,821	1,821	0	3,969	42
Jul.	0	111,091	141,834	78,238	1,882	1,882	0	4,101	43
Aug.	0	111,296	141,834	78,238	1,882	1,882	0	4,101	43
Sep.	0	116,334	139,449	76,923	1,821	1,821	0	3,969	206
Oct.	7,978	106,786	144,663	79,799	1,882	1,882	0	4,101	213
Nov.	8,104	102,998	139,532	76,969	1,821	1,821	0	3,402	206
Dec.	0	63,447	85,894	47,365	1,882	1,882	0	1,465	213
<b>Total</b>	74,648	1,159,016	1,524,991	841,169	22,220	22,220	0	39,529	1,843



**Table D.5. Monthly nonpoint fecal coliform loadings to the different land-use categories in the subwatershed MLC-E of the Mill Creek watershed**

Month	Fecal coliform loadings ( $\times 10^9$ cfu/month)								
	Crop-land	Pasture 1	Pasture 2	Pasture 3	Rural Residential	Farmstead	Urban Residential	Loafing lot	Forest
Jan.	0	71,539	10,888	78,499	1,817	1,817	251	0	45
Feb.	5,808	66,923	10,186	73,434	1,700	1,700	235	0	42
Mar.	29,038	121,141	18,449	133,048	1,817	1,817	251	0	45
Apr.	23,230	118,192	18,000	129,811	1,758	1,758	243	0	43
May	5,808	121,587	18,517	133,539	1,817	1,817	251	0	45
Jun.	0	123,002	17,599	126,913	1,758	1,758	243	0	43
Jul.	0	126,354	18,185	131,144	1,817	1,817	251	0	45
Aug.	0	126,604	18,185	131,144	1,817	1,817	251	0	45
Sep.	0	132,306	17,920	129,232	1,758	1,758	243	0	43
Oct.	8,686	122,132	18,600	134,138	1,817	1,817	251	0	45
Nov.	8,840	117,233	17,854	128,757	1,758	1,758	243	0	43
Dec.	0	71,539	10,888	78,499	1,817	1,817	251	0	45
<b>Total</b>	81,410	1,318,552	195,273	1,408,157	21,453	21,453	2,965	0	531

**Table D.6. Monthly nonpoint fecal coliform loadings to the different land-use categories in the subwatershed MLC-F of the Mill Creek watershed**

Month	Fecal coliform loadings ( $\times 10^9$ cfu/month)								
	Crop-land	Pasture 1	Pasture 2	Pasture 3	Rural Residential	Farmstead	Urban Residential	Loafing lot	Forest
Jan.	0	23,583	9,417	13,789	11,520	11,520	6,724	0	4,339
Feb.	4,122	23,029	9,003	13,042	10,777	10,777	6,290	0	2,252
Mar.	20,609	40,220	15,878	23,117	11,520	11,520	6,724	0	2,351
Apr.	16,487	38,923	15,365	22,371	11,149	11,149	6,507	0	2,275
May	4,122	40,220	15,878	23,117	11,520	11,520	6,724	0	2,351
Jun.	0	44,029	15,365	22,371	11,149	11,149	6,507	0	2,166
Jul.	0	45,327	15,878	23,117	11,520	11,520	6,724	0	2,238
Aug.	0	45,327	15,878	23,117	11,520	11,520	6,724	0	2,238
Sep.	0	49,136	15,365	22,371	11,149	11,149	6,507	0	2,330
Oct.	6,274	40,220	15,878	23,117	11,520	11,520	6,724	0	2,407
Nov.	6,274	39,923	15,566	22,518	11,149	11,149	6,507	0	4,199
Dec.	0	25,651	9,831	14,093	11,520	11,520	6,724	0	4,339
<b>Total</b>	57,888	455,588	169,300	246,141	136,015	136,015	79,385	0	33,483

## **APPENDIX E**

### **Required Reductions in Fecal Coliform Loads by Subwatershed – Allocation Scenario**

**Table E.1a. Required annual reductions in nonpoint sources in subwatershed MLC-A**

<b>Land-use</b>	<b>Existing conditions load (<math>\times 10^9</math> cfu)</b>	<b>Percent of total load from nonpoint sources</b>	<b>TMDL nonpoint source allocation load (<math>\times 10^9</math> cfu)</b>	<b>Percentage reduction</b>
<b>Cropland</b>	945.2	2.8	945.2	0
<b>Pasture 1</b>	32,421.1	96.0	32,421.1	0
<b>Pasture 2</b>	240.9	0.7	240.9	0
<b>Pasture 3</b>	98.7	0.3	98.7	0
<b>Rural Residential</b>	41.1	0.1	41.1	0
<b>Farmstead</b>	5.6	0.0	5.6	0
<b>Urban Residential</b>	0.0	0.0	0.0	0
<b>Loafing lot</b>	0	0	0	0
<b>Forest</b>	1.1	0.0	1.1	0
<b>Total</b>	33,754.0	100.0	33,754.0	0

**Table E.1b. Required annual reductions in direct nonpoint sources in subwatershed MLC-A**

<b>Source</b>	<b>Existing conditions load (<math>\times 10^9</math> cfu)</b>	<b>Percent of total load from direct nonpoint sources</b>	<b>TMDL direct nonpoint source allocation load (<math>\times 10^9</math> cfu)</b>	<b>Percentage reduction</b>
<b>Cattle in streams</b>	7,983	97.1	0	100.0
<b>Wildlife in streams</b>	236	2.9	70.8	70.0
<b>Total</b>	8,219	100.0	70.8	99.1

**Table E.2a. Required annual reductions in nonpoint sources in subwatershed MLC-B**

<b>Land-use</b>	<b>Existing conditions load (<math>\times 10^9</math> cfu)</b>	<b>Percent of total load from nonpoint sources</b>	<b>TMDL nonpoint source allocation load (<math>\times 10^9</math> cfu)</b>	<b>Percentage reduction</b>
<b>Cropland</b>	29,127.0	2.9	29,127.0	0
<b>Pasture 1</b>	928,906.0	94.8	928,906.0	0
<b>Pasture 2</b>	10,939.9	1.1	10,939.9	0
<b>Pasture 3</b>	4,704.6	0.5	4,704.6	0
<b>Rural Residential</b>	5,836.6	0.6	5,836.6	0
<b>Farmstead</b>	0.0	0.0	0.0	0
<b>Urban Residential</b>	0.0	0.0	0.0	0
<b>Loafing lot</b>	0	0.0	0	0
<b>Forest</b>	48.4	0.0	48.4	0
<b>Total</b>	979,561.6	100.0	979,561.6	0

**Table E.2b. Required annual reductions in direct nonpoint sources in subwatershed MLC-B**

<b>Source</b>	<b>Existing conditions load (<math>\times 10^9</math> cfu)</b>	<b>Percent of total load from direct nonpoint sources</b>	<b>TMDL direct nonpoint source allocation load (<math>\times 10^9</math> cfu)</b>	<b>Percentage reduction</b>
<b>Cattle in streams</b>	21,704	96.8	0	100.0
<b>Wildlife in streams</b>	715	3.2	214.5	70.0
<b>Total</b>	22,419	100.0	214.5	99.0

**Table E.3a. Required annual reductions in nonpoint sources in subwatershed MLC-C**

<b>Land-use</b>	<b>Existing conditions load (<math>\times 10^9</math> cfu)</b>	<b>Percent of total load from nonpoint sources</b>	<b>TMDL nonpoint source allocation load (<math>\times 10^9</math> cfu)</b>	<b>Percentage reduction</b>
<b>Cropland</b>	26,850.1	69.6	26,850.1	0
<b>Pasture 1</b>	0.0	0.0	0.0	0
<b>Pasture 2</b>	4,435.1	11.2	4,435.1	0
<b>Pasture 3</b>	1,891.1	4.9	1,891.1	0
<b>Rural Residential</b>	3,899.0	10.1	3,899.0	0
<b>Farmstead</b>	1,606.1	4.2	1,606.1	0
<b>Urban Residential</b>	0.0	0.0	0.0	0
<b>Loafing lot</b>	0.0	0.0	0.0	0
<b>Forest</b>	0.2	0.0	0.2	0
<b>Total</b>	38,591.6	100.0	38,591.6	0

**Table E.3b. Required annual reductions in direct nonpoint sources in subwatershed MLC-C**

<b>Source</b>	<b>Existing conditions load (<math>\times 10^9</math> cfu)</b>	<b>Percent of total load from direct nonpoint sources</b>	<b>TMDL direct nonpoint source allocation load (<math>\times 10^9</math> cfu)</b>	<b>Percentage reduction</b>
<b>Cattle in streams</b>	15,455	96.5	0	100.0
<b>Wildlife in streams</b>	555	3.5	166.5	70.0
<b>Total</b>	16,010	100.0	166.5	98.9

**Table E.4a. Required annual reductions in nonpoint sources in subwatershed MLC-D**

<b>Land-use</b>	<b>Existing conditions load (<math>\times 10^9</math> cfu)</b>	<b>Percent of total load from nonpoint sources</b>	<b>TMDL nonpoint source allocation load (<math>\times 10^9</math> cfu)</b>	<b>Percentage reduction</b>
<b>Cropland</b>	6,319.0	2.3	6,319.0	0
<b>Pasture 1</b>	129,290.0	47.7	129,290.0	0
<b>Pasture 2</b>	73,058.7	42.6	73,058.7	0
<b>Pasture 3</b>	31,679.3	7.1	31,679.3	0
<b>Rural Residential</b>	205.6	0.1	205.6	0
<b>Farmstead</b>	162.3	0.1	162.3	0
<b>Urban Residential</b>	0.0	0.0	0.0	0
<b>Loafing lot</b>	136.2	0.0	136.2	0
<b>Forest</b>	20.5	0.0	20.5	0
<b>Total</b>	240,709.3	100.0	240,709.3	0

**Table E.4b. Required annual reductions in direct nonpoint sources in subwatershed MLC-D**

<b>Source</b>	<b>Existing conditions load (<math>\times 10^9</math> cfu)</b>	<b>Percent of total load from direct nonpoint sources</b>	<b>TMDL direct nonpoint source allocation load (<math>\times 10^9</math> cfu)</b>	<b>Percentage reduction</b>
<b>Cattle in streams</b>	45,706	97.4	0	100.0
<b>Wildlife in streams</b>	1,224	2.6	367.2	70.0
<b>Total</b>	46,930	100.0	367.2	99.2

**Table E.5a. Required annual reductions in nonpoint sources in subwatershed MLC-E**

<b>Land-use</b>	<b>Existing conditions load (<math>\times 10^9</math> cfu)</b>	<b>Percent of total load from nonpoint sources</b>	<b>TMDL nonpoint source allocation load (<math>\times 10^9</math> cfu)</b>	<b>Percentage reduction</b>
<b>Cropland</b>	12,121.4	6.2	12,121.4	0
<b>Pasture 1</b>	160,949.8	82.5	160,949.8	0
<b>Pasture 2</b>	14,904.9	7.6	14,904.9	0
<b>Pasture 3</b>	6,604.6	3.4	6,604.6	0
<b>Rural Residential</b>	162.7	0.1	162.7	0
<b>Farmstead</b>	260.4	0.1	260.4	0
<b>Urban Residential</b>	14.7	0.0	14.7	0
<b>Loafing lot</b>	0.0	0.0	0.0	0
<b>Forest</b>	6.2	0.0	6.2	0
<b>Total</b>	195,024.7	100.0	195,024.7	0

**Table E.5b. Required annual reductions in direct nonpoint sources in subwatershed MLC-E**

<b>Source</b>	<b>Existing conditions load (<math>\times 10^9</math> cfu)</b>	<b>Percent of total load from direct nonpoint sources</b>	<b>TMDL direct nonpoint source allocation load (<math>\times 10^9</math> cfu)</b>	<b>Percentage reduction</b>
<b>Cattle in streams</b>	43,231	99.5	0	100.0
<b>Wildlife in streams</b>	211	0.5	63.3	70.0
<b>Total</b>	43,442	100.0	63.3	99.8



**Table E.6a. Required annual reductions in nonpoint sources in subwatershed MLC-F**

<b>Land-use</b>	<b>Existing conditions load (<math>\times 10^9</math> cfu)</b>	<b>Percent of total load from nonpoint sources</b>	<b>TMDL nonpoint source allocation load (<math>\times 10^9</math> cfu)</b>	<b>Percentage reduction</b>
<b>Cropland</b>	2,484.7	2.3	2,484.7	0
<b>Pasture 1</b>	5,6197.5	52.9	5,6197.5	0
<b>Pasture 2</b>	7,201.1	6.8	7,201.1	0
<b>Pasture 3</b>	3,069.9	2.9	3,069.9	0
<b>Rural Residential</b>	22,043.0	20.8	22,043.0	0
<b>Farmstead</b>	718.9	0.8	718.9	0
<b>Urban Residential</b>	10,565.2	0.9	10,565.2	0
<b>Loafing lot</b>	0.0	0.0	0.0	0
<b>Forest</b>	3,865.5	3.6	3,865.5	0
<b>Total</b>	106,145.8	100.0	106,145.8	0

**Table E.6b. Required annual reductions in direct nonpoint sources in subwatershed MLC-F**

<b>Source</b>	<b>Existing conditions load (<math>\times 10^9</math> cfu)</b>	<b>Percent of total load from direct nonpoint sources</b>	<b>TMDL direct nonpoint source allocation load (<math>\times 10^9</math> cfu)</b>	<b>Percentage reduction</b>
<b>Cattle in streams</b>	0	0.0	0	0.0
<b>Wildlife in streams</b>	7,900	100.0	2,370	70.0
<b>Total</b>	7,900	100.0	2,370	70.0

## **APPENDIX F**

**- Response to EPA Comments -**

**September 2000**

## **Summary of Changes to the Mill Creek, Pleasant Run and Dry River TMDL Reports for September 2000 Submittal**

On May 1, 2000, the Commonwealth submitted to the US Environmental Protection Agency (EPA) the fecal coliform TMDLs developed for Mill Creek, Pleasant Run and Dry River in Rockingham County, Virginia. These TMDLs, together with eight others, were subsequently retracted due to a number of concerns raised by EPA (e-mails dated 3/11/00 and April 2000, letter dated 5/18/00). The Commonwealth has incorporated modifications to the TMDLs that resulted from communications with EPA. This document outlines the alterations and additions for each TMDL report.

For the Mill Creek TMDL, two HSPF calibration parameters (INTFW and INFILT) were changed in order to improve flow partitioning in the hydrology calibration. To reflect this, a paragraph describing the parameter values for INTFW and INFILT was inserted on page 57 of the report. On the same page, the resulting flow partitioning values were added. Two more HSPF parameters, AOQC and IOQC, were modified to reflect more reasonable fecal coliform concentrations in groundwater and interflow. The IOQC and AOQC values in table 5.10 were changed accordingly.

The parameter changes resulted in slightly different loads and concentrations, and consequently in a small increase of the wildlife reduction (70% instead of 60%). Tables 1.1 through 1.4, 6.1 through 6.5, 7.1 through 7.3 as well as all tables in Appendix E were modified with the concentrations, loads and percent reduction resulting from the new parameters. Figures 1.1, 5.4, 5.5, 6.1, 6.2, and 7.1 were replaced by the new model plots. Also, the corresponding text passages were revised.

Additionally, table 3.4 and figure 3.6 showing average monthly flows were inserted in chapter 3.6.1. Two paragraphs (from e-mail dated 5/22/00) regarding storage issues and manure application were incorporated in chapters 5.4.2 and 5.4.3 respectively.

For the Pleasant Run TMDL, a sentence describing flow partitioning was added on page 56. Table 5.10 was changed to reflect changed values for IOQC and AOQC, which resulted in slightly different loads and concentrations, and consequently in a small increase of the wildlife reduction (15% instead of 10%). This increase did not result in any changes to tables 1.2 and 1.4, 6.1, 6.3 or 6.5, 7.1 through 7.3 or to the tables in

Appendix E. However, tables 1.1, 1.3, 6.2 and 6.4 were modified with the percent reduction resulting from the new parameters. Figures 1.1, 6.1, and 7.1 were replaced with the new model plots. Also, the corresponding text passages were revised. Table 3.4 and figure 3.6 showing average monthly flows were inserted in chapter 3.6.1. Two paragraphs (from e-mail dated 5/22/00) regarding storage issues and manure application were incorporated in chapters 5.4.2 and 5.4.3 respectively

For the Dry River TMDL, a sentence describing flow partitioning was added on page 64. INTFW and INFILT were the not changed, but a justification for these values was added as Appendix F. Table 5.10 was modified to reflect changed values for IOQC and AOQC. These changed values did not result in any changes to the concentrations, loads and percent reduction in tables 1.1 through 1.4, 6.1 through 6.5, 7.1 through 7.3 or to the tables in Appendix E. Also, the original figures 1.1, 5.4, 5.5, 6.1, 6.2, and 7.1 were retained. Table 3.4 and figure 3.6 showing average monthly flows were inserted in chapter 3.6.1. Two paragraphs (from e-mail dated 5/22/00) regarding storage issues and manure application were incorporated in chapters 5.4.2 and 5.4.3 respectively.

The following section describes each alteration to the Mill Creek TMDL Report individually.

#### **Individual Changes to the Mill Creek TMDL Report**

- **Page 4** - Table 1.1, put in new values and changed text to correspond.
- **Page 5** - Replaced Figure 1.1, changed values in Table 1.2
- **Page 6** - Table 1.3 , and Table 1.4 values changed
- **Page 18** - Added Table 3.4 and Figure 3.3, updated section 3 table and figure numbers
- **Section 5.4.2** (page 46) – the following was added “The method used to calculate the fraction of fecal coliform surviving in the manure at the end of storage considered the duration of storage, type of storage, type of manure, and die-off factor. When calculating survival fraction at the end of the storage period, the daily addition of manure and coliform die-off of each fresh manure addition is considered to arrive at an effective survival fraction over the entire storage period. The amount of fecal coliform available for application to land per year is estimated by multiplying the survival fraction with total fecal coliform produced per year (in as-excreted manure). Monthly fecal coliform application to land was estimated by multiplying the amount of

fecal coliform available for application to land per year by the fraction of manure applied to land during that month.”

- **Section 5.4.3** (page 47) – the following was added “Total manure production was calculated using animal population and waste produced per day per animal. Animal numbers for the watershed were supplied by VADCR. These numbers were further refined by consulting with producers and Virginia Cooperative Extension faculty located in that county. The refined animal numbers were also checked against pasture acreage (for beef) and housing capacity (for poultry) to ensure that the estimates were reasonable. For dairy cattle population, the number of dairies in each subwatershed and the number of dairy cattle in each dairy farm were estimated in consultation with producers. The numbers on daily waste production from different animal species were obtained from published sources such as the ASAE Standards or Virginia Nutrient Management Standards Criteria. Estimation of manure produced in different locations (e.g., confinement, pastures) were based on guidelines provided by VADCR which were confirmed or modified through discussion with producers and extension personnel.”
- **Page 58** - the following sentences were added:  
“The final values for infiltration index parameter (INFILT) and interflow inflow (INTFLW) were 0.15, and 1.8, respectively.”  
“Partitioning of the total flow indicated that surface flow (SURO), interflow (IFWO), and active groundwater (AGWO) accounted for 15.08%, 37.48%, and 47.44% of the flow, respectively.”
- **Page 59 and 60** - Replaced Figures 5.4 and 5.5
- **Page 61** – Table 5.10. IOQC and AOQC values were changed
- **Page 63** - Replaced values in Table 6.1, changed percentages in text.
- **Page 64** - Table 6.2, Scenario 4, wildlife deposition, changed percentages in text.
- **Pages 65 and 66** - Replaced Figures 6.1, changed percentage in text.
- **Page 66** - replaced figure 6.2 ,updated values in table 6.3
- **Page 67** - updated Table 6.4
- **Page 68** - updated values in Table 6.5
- **Page 71** - Table 7.1, Scenario 4 cattle deposits
- **Page 71** - updated Table 7.2
- **Page 72** - updated Table 7.3
- **Page 73** - Replaced Figure 7.1

- **Page 105** - Updated Table E.1b
- **Page 106** - Updated Table E.2b
- **Page 107** - Updated Table E.3b
- **Page 108** - Updated Table E.4b
- **Page 111** – Added Response to EPA Comments as Appendix F